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AN ANALYSIS OF THE ARC AND SPARK SPECTRA OF SCANDIUM (Sc I AND Sc II)

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ABSTRACT

In the present analysis spectral term combinations have been assigned to 353 lines of Sc I and 142 of Sc II. Nearly all of the observed lines in both spectra are thus classified.

Details of the spark spectrum (Sc II) are presented first because they are simpler. The terms with lowest energy content are ^3D, ^1D, arising from the electron configuration $3d.4s$. Next come $^3F'$, $^3P'$, ^1S, ^1D, ^1G from $3d.3d$. All these terms combine with ^3P, $^3D'$, ^3F; ^1P, $^1D'$, ^1F from $3d.4p$; and these again with ^3S, $^3P'$, ^3D, $^3F'$, ^3G; ^1S, $^1P'$, ^1D, $^1F'$, ^1G from $3d.4d$, and ^3D, ^1D from $3d.5s$. The last are in series with the lowest terms, and the ionization potential of the Sc^+ atom is indicated by these series to be 12.8 volts. A ^3P term arising from $4s.4p$ and a $^3P'$ term from $4p.4p$ are also present.

The arc spectrum (Sc I) is much more complex. The lowest-energy term, representing the normal state of the Sc atom, is ^2D, which originates with the three-electron configuration $3d.4s.4s$. Next follow the metastable states $^4F'$, $^2F'$, ^2D, ^2G, $^4P'$ arising from $3d.3d.4s$. The configurations $3d.4s.4p$ and $3d.3d.4p$ give numerous "middle" terms combining with the low ones and also with higher terms arising from $3d.4s.5s$, $3d.3d.5s$, $3d.3d.3d$, $3d.4s.4d$ and $3d.4p.4p$. The two terms first mentioned, ^2D and $^4F'$, begin two series from which an ionization potential of 6.7 volts is obtained for the neutral Sc atom.

The theoretical interpretation of the observed terms is outlined, and all details of the structure of both arc and spark spectra are found to be in complete agreement with Hund's theory, which derives one or more specific spectral terms from each possible configuration of the electrons not in completed groups.

Results of this analysis are presented in the form of term tables, multiplet tables, tables of classified lines, and energy diagrams for each of the spectra.

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I. INTRODUCTION

Scandium is the lightest element which exhibits a spectrum of the type characteristic of the heavier metals, in which the lines are very numerous, multiplets are abundant, and series inconspicuous. The first step toward analysis of its spectrum was made by Popow,[1] who identified a PD group in the ultra-violet, belonging to a triplet system. Later, Catalán [2] found a number of additional multiplets of the triplet system in the spark spectrum, and detected doublets and quartets in the arc spectrum. His analysis was extended, and some of his conclusions corrected by Meggers,[3] who showed that the state of lowest energy in the neutral atom corresponds to a ^2D term, and the next lowest state to a $^4F'$ [4] though the relative levels of these terms were not exactly assignable, since no intercombinations between the systems were found.

In the singly ionized atom, the lowest term was found to be a ^3D, with a $^3F'$ and $^3P'$ somewhat higher. Transitions ending in these atomic states account for most, though not all, of the more prominent arc and spark lines. Many important lines, and numerous fainter ones, were, however, left unclassified.

More recently Hund [5] has accounted for these terms, in a very satisfactory manner, by means of his theory of atomic and spectral structure; and Gibbs and White [6] and Stanley Smith [7] have identified the most important terms in the spectrum of the doubly ionized atom (Sc III) and shown that the ^2D term is here the lowest, as surmised years before by Bohr.[8]

The present analysis, begun some time ago by one of us (W. F. M.) and delayed by pressure of other duties, has been completed by the other. The number of lines whose relations have been identified is 142 for Sc II and 353 for Sc I. Were it not for the scarcity of scandium, which makes it impracticable to use long exposures in the search for faint lines, these numbers could probably be considerably increased. As it is, only a few scattered lines of small intensity remain unclassified, and the analysis may be regarded as practically complete, under the existing limitations. It has been possible to interpret almost all the terms which have been found, by means of Hund's theory, to identify the corresponding atomic configurations with security, and thus to find the beginnings of series, which lead to the determination of the ionization potentials for the removal of both the first and the second valency electrons.

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[1] Ann. d Phys., 45, p. 163; 1914.
[2] An. Soc. Esp. d Fis. y Quim., 20, p. 606; 1922. Ibid., 21, p. 464; 1923.
[3] Proc. Wash. Acad. Sci., 14, p. 419; 1924. Ibid., 17, p. 33; 1927.
[4] For an explanation of the use of the accents, see p. 360.
[5] Zs. f. Physik, 33, pp. 350, 363; 1925.
[6] Proc. Nat. Acad. Sci., 12, p. 598; 1926.
[7] Proc. Nat. Acad. Sci., 13, p. 66; 1927.
[8] Zs. f. Phys., 9, p. 46 ff; 1922.

In presenting the results, the spark spectrum, which is much the simpler of the two, may best be considered first.

II. THE SPARK SPECTRUM (Sc II)

The spectrum of singly ionized scandium is easy to produce. Fowler [9] pointed out that practically all the enhanced lines appeared in the arc, and King [10] found many of them in the furnace—the strongest appearing at moderate temperatures, and being placed in Class III of his temperature classification. These conclusions have been confirmed in the present investigation, which shows that all the lines which might theoretically be expected in the second spectrum are present in the arc. Many of these were identifiable at once as enhanced lines by the familiar characteristic of appearance only near the negative electrode.

There are many lines in the ultra-violet, strongly enhanced in the spark. These have been found to represent combinations between the triad just mentioned and a group of still higher levels—^3S, $^3P'$, ^3D, $^3F'$, ^3G, and an additional ^3D. The five terms first mentioned are evidently closely related, and their combinations with the triad ^3P, $^3D'$, ^3F can be arranged in the form of a "supermultiplet" as follows:

	a^3F_4	a^3F_3	a^3F_2	$a^3D'_3$	$a^3D'_2$	$a^3D'_1$	a^3P_2	a^3P_1	a^3P_0
	(30c)								
a^3G_5	32,615.80								
	(3c)	(20c)							
a^3G_4	32,506.89	32,746.03							
		(3c)	(15c)						
a^3G_3		32,664.61	32,823.33						
	(6c)			(10c)					
$b^3F'_4$	35,686.58			35,366.68					
	(1c)	(5c)		(1c)	(7c)				
$b^3F'_3$	35,603.21	35,842.02		35,283.47	35,423.32				
		(1c)	(3c)		(2c)	(5c)			
$b^3F'_2$		35,771.49	35,930.40		35,352.68	35,456.11			
	(3c)			(10c)	(1c)		(5c)		
c^3D_3	32,160.06			31,840.37	31,980.32		30,177.74		
		(2c)		(1c)	(8c)	(3c)	(1c)	(3c)	
c^3D_2		32,326.72		31,768.03	31,907.85	32,011.45	30,105.33	30,187.04	
			(2c)		(1c)	(5c)		(1c)	(1c)
c^3D_1			32,431.07		31,853.58	31,957.11		30,132.72	30,138.52
				(1c)			(4c)	(2c)	
$b^3P'_2$				36,544.12			34,881.13	34,963.11	
					(1c)		(2c)	(1c)	(2c)
$b^3P'_1$					36,624.58		34,822.09	34,904.15	34,910.00
						(1c)		(2c)	
$b^3P'_0$						36,697.71		34,872.58	
							(10c)	(5c)	(2c)
a^3S_1							31,247.06	31,329.01	31,334.90

It is noteworthy that the strong pair of Sc III at λλ2,699.12, 2,734.10 appear in this arc spectrum with considerable intensities (6

[9] A. Fowler, Phil. Trans. A., **209**, p. 47; 1909.
[10] A. S. King, Ap. J., **54**, p. 39; 1921.

and 4). This is unusual, and rather unexpected, but not hard to explain, for these lines, though not the ultimate lines of the third spectrum, are easy to excite and should appear with much less provocation than the lines of almost any other doubly ionized atom.

Most of the stronger lines of Sc II arise from the combinations between the low ^3D, $^3F'$, $^3P'$ terms and a "triad," ^3F, $^3D'$, ^3P, lying about 28,000 wave numbers higher. A ^3P term at a considerably higher level accounts for Popow's group and completes the list of terms previously identified.

The observed and computed positions of the lines in all these multiplets agree satisfactorily, and it is of much interest to note that the relative intensities of the different multiplets are very much the same as those of the component lines of an ordinary PD multiplet, in which each term has its full number of components. Taking the sum of the estimated intensities of all the lines of each multiplet and comparing with the theoretical intensities for a $^6P^6D$ group [11] (reduced to the same sum), we find the following:

Observed			Theory		
71			63		
16	25		18	32	
7	29	10	3	23	12
	3	13		7	18
		17			13

The agreement is remarkable, considering the inevitably rough character of even careful estimates of line intensity on ordinary photographs, and suggests that a precise photometric measurement of intensities in these and similar groups would be well worth while. One additional multiplet of the triplet system has been identified—a combination of Popow's high ^3P term with a $^3P'$ term, which has the highest energy of any so far found in this spectrum.

Some of the strongest lines of Sc II are isolated and obviously belong to a singlet system. The most noteworthy of these, at λ4247, was identified, by means of intercombinations, as corresponding to a transition between a low ^1D term, only 2,500 units above the base-level ^3D, and a $^1D'$ term. The ^1P and ^1F terms, which make up a triad with this, were next found. They combine with the ^1D term and give strong lines in the ultra-violet (which, like λ4247, appear in the furnace) and with a higher ^1D term to give lines in the visible region. A ^1S term, at about the same level as the last, was next identified by its combinations with the ^1P and ^3P terms; and some ultra-violet lines were assigned to transitions from the P D′ F triad to a higher level. This leaves outstanding only one conspicuous

[11] H. N. Russell, Proc. Nat. Acad. Sci., **11**, 326; 1925.

enhanced line, at λ5527, the strongest in the visual region. No combinations could be found to identify this, but it appears practically certain that it arises from a low ^{1}G term, which is to be expected theoretically, and combines with the ^{1}F of the triad. Its combinations with the corresponding ^{3}F term are in the deep red, and should be faint and hard to find. This interpretation is confirmed by analogy with La II. In this spectrum—the analysis of which is well forward by one of us (W. F. M.), but not fully completed—the intersystem combinations are much stronger, and establish the existence of the ^{1}G term beyond question; and the line ^{1}G–^{1}F is very strong. A number of lines in the ultra-violet, some of which are strong, appear to be combinations between the triad P D′ F of singlet terms and a group of five higher terms, S, P′, D, F′, G, which, with an additional ^{1}D term, are evidently analogous to the high triplet terms previously described.

The terms which have so far been identified are listed in Table 1. The term values are measured upward from the lowest known energy level a^3D_1, which is undoubtedly the lowest in the ionized atom. The notation for the terms is that now generally adopted. Terms of the same kind are distinguished by the letters *a*, *b*, etc., which are attached to them in order, beginning with the lowest, thus the four singlet D terms are a^1D, b^1D, c^1D, d^1D. The small letters have, therefore, no significance except as convenient labels, and are not intended to suggest anything at all about series relations. As misunderstandings have sometimes arisen on this point, an explicit statement is desirable.

The terms and combinations for the Sc II spectrum are shown diagrammatically in Figure 1.

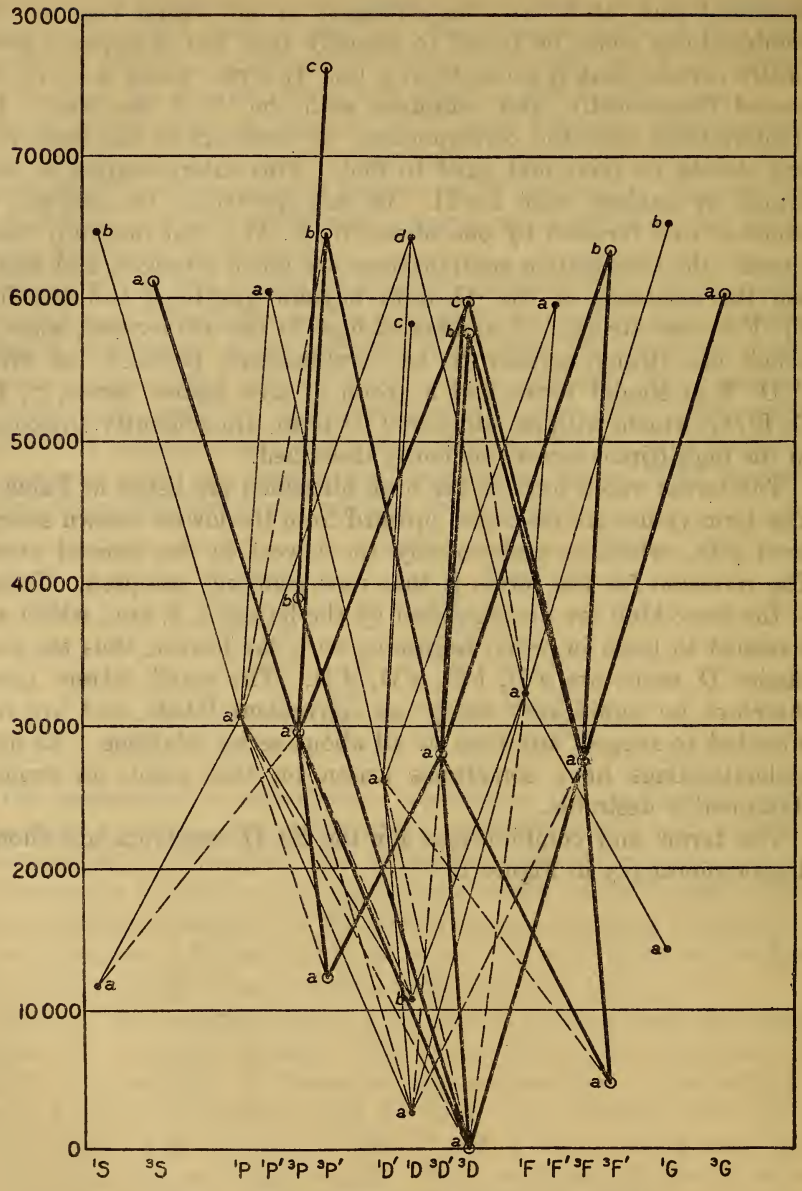


FIG. 1.—*Energy diagram for the Sc II spectrum*

Black dots represent singlet terms, circles triplet terms. Light lines represent singlet-singlet combinations, heavy lines triplet-triplet, and broken lines singlet-triplet combinations.

TABLE 1.—*Relative terms in the Sc II spectrum*

Level	Term	Δ ν	Combinations	Level	Term	Δ ν	Combinations
0.00	a^3D_1			39,001.59	b^3P_0		
		67.68				112.85	
67.68	a^3D_2		a^3P, b^3P, a^3D', a^3F	39,114.44	b^3P_1		c^3P', a^3D.
		109.95	a^1P, a^1D', a^1F.			230.46	
177.63	a^3D_3			39,344.90	b^3P_2		
2,540.97	a^1D_2		a^1P, a^1D', a^1F, a^3P, a^3D', a^3F.	57,551.46	b^3D_1		
						62.48	
				57,613.94	b^3D_2		a^3D', a^3F. a^1D'.
4,802.75	$a^3F'_2$					129.43	
		80.67		57,743.37	b^3D_3		
4,883.42	$a^3F'_3$		a^3D', a^3F, a^1D'.				
		104.22		58,251.92	c^1D_2		a^1D'.
4,987.64	$a^3F'_4$						
				59,528.22	$a^1F'_3$		a^1D', a^1F.
10,944.51	b^1D_2		a^1P, a^1D', a^1F, a^3P.	59,874.79	c^3D_1		
						54.39	
11,736.35	a^1S_0		a^1P, a^3P.	59,929.18	c^3D_2		a^3P, a^3D', a^3F.
						72.42	
12,074.00	$a^3P'_0$			60,001.60	c^3D_3		
		27.45					
12,101.45	$a^3P'_1$		a^3P, a^3D', a^1P.	60,266.95	a^3G_3		
		52.89				81.25	
12,154.34	$a^3P'_2$			60,348.20	a^3G_4		a^3F.
						108.77	
14,261.40	a^1G_4		a^1F.	60,456.97	a^3G_5		
26,081.32	$a^1D'_2$		a^1P', a^1D, b^1D, c^1D, d^1D, a^1F', a^3D, b^3D, a^3F'.	60,400.02	$a^1P'_1$		a^1P, a^1D'.
				61,071.10	a^3S_1		a^3P.
27,443.65	a^3F_2			63,373.91	$b^3F'_2$		
		158.67				70.52	
27,602.32	a^3F_3		a^3D, b^3D, c^3D, a^3F', b^3F', a^3G, a^1D.	63,444.43	$b^3F'_3$		a^3D', a^3F.
		238.85				83.30	
27,841.17	a^3F_4			63,527.73	$b^3F'_4$		
27,917.69	$a^3D'_1$			64,366.15	d^1D_2		a^1P, a^1D', a^1F.
		103.52	a^3P', b^3P', a^3D, b^3D, c^3D, a^3F', b^3F', a^1D.	64,615.28	$b^3P'_0$		
28,021.21	$a^3D'_2$					30.80	
		139.82		64,646.08	$b^3P'_1$		a^3P, a^3D', a^1P.
28,161.03	$a^3D'_3$					59.08	
				64,705.16	$b^3P'_2$		
29,736.22	a^3P_0			64,942.79	b^1S_0		a^1P.
		5.90	a^3S, a^3P', b^3P', a^3D, c^3D, a^1D, a^1S.				
29,742.12	a^3P_1			65,235.83	b^1G_4		a^1F.
		81.80					
29,823.92	a^3P_2			76,242.40	$c^3P'_0$		
						117.41	
30,815.65	a^1P_1		a^1S, b^1S, a^1P', a^1D, b^1D, d^1D, a^3P', b^3P', a^3D.	76,359.81	$c^3P'_1$		b^3P.
						228.67	
				76,588.48	$c^3P'_2$		
32,349.98	a^1F_3		a^1D, b^1D, d^1D, a^1F', a^1G, a^3D.				

Table 2 exhibits the multiplets which have been found. Only the wave numbers and intensities of the lines are given, and the group of combinations of triplet terms which has previously been given (cf. p. 331) is not repeated.

TABLE 2.—*Combinations in the Sc II spectrum*

	a^3D_3	a^3D_2	a^3D_1	a^1D_2	$a^3F'_4$	$a^3F'_3$	$a^3F'_2$
		4	3	100 III E			2
$a^1D'_2$	(25, 963. 69)	26, 013. 58	26, 081. 31	23, 540. 37		(21, 197. 90)	21, 278. 36
	60 II				40 III E	5 V E	
a^3F_4	27, 663. 54				22, 853. 56	22, 957. 79	
	30 III	50 II		2	2	30 III E	6 IV E
a^3F_3	27, 424. 72	27, 534. 62		25, 061. 50	22, 614. 72	22, 718. 95	22, 799. 67
	3 III	25 III	40 II	5 IV E		3 V E	20 III E
a^3F_2	27, 265. 93	27, 375. 98	27, 443. 69	24, 902. 75		22, 560. 17	22, 640. 90
	50 II	20 II			60 III E	8 IV E	1
$a^3D'_3$	27, 983. 41	28, 093. 34			23, 173. 37	23, 277. 61	23, 358. 21
	20 II	35 II	20 II	2		50 III E	10 IV E
$a^3D'_2$	27, 843. 51	27, 953. 52	28, 021. 29	25, 480. 19		23, 137. 75	23, 218. 46
		20 II	30 II				40 III E
$a^3D'_1$		27, 850. 03	27, 917. 69				23, 114. 91
	20 III	10 III	3 IV	1			
a^3P_2	29, 646. 27	29, 756. 22	29, 823. 95	27, 282. 97		(24, 940. 50)	
		15 III	10 III	1			
a^3P_1		29, 674. 43	29, 742. 23	27, 201. 24			(24, 940. 12)
			12 III				
a^3P_0			29, 736. 22				
		3 IV		10 III			
a^1P_1		30, 747. 99		28, 274. 65			
	1			25 III			
a^1F_3	32, 172. 04			29, 809. 01	(27, 362. 36)	(27, 466. 56)	(27, 547. 23)

	$a^3P'_2$	$a^3P'_1$	$a^3P'_0$	a^1S_0	b^1D_2	a^1G_4
					10	
$a^1D'_2$	(13, 926. 98)	(13, 979. 87)			15, 136. 79	
a^3F_4						(13, 579. 77)
a^3F_3	(15, 447. 98)				(16, 657. 81)	(13, 340. 92)
a^3F_2		(15, 342. 20)			(16, 499. 14)	
	20 V E					
$a^3D'_3$	16, 006. 75					(13, 899. 63)
	6	15				
$a^3D'_2$	15, 866. 87	15, 919. 83			(17, 076. 60)	
	0	7	15			
$a^3D'_1$	15, 763. 34	15, 816. 27	15, 843. 74	(16, 181. 34)		
	25 V E	15 V E				
a^3P_2	17, 669. 54	17, 722. 48			(18, 879. 40)	
	15 V E	10 V E	8 V E	3	3 IV E	
a^3P_1	17, 587. 73	17, 640. 64	17, 668. 11	18, 005. 73	18, 797. 60	
		12 IV E				
a^3P_0		17, 634. 76				
	2		2 IV A	15 IV E	40 V E	
a^1P_1	18, 661. 36	(18, 714. 25)	18, 741. 68?	19, 079. 36	19, 871. 16	
					15 IV E	75 V E
a^1F_3					21, 405. 47	18, 088. 58

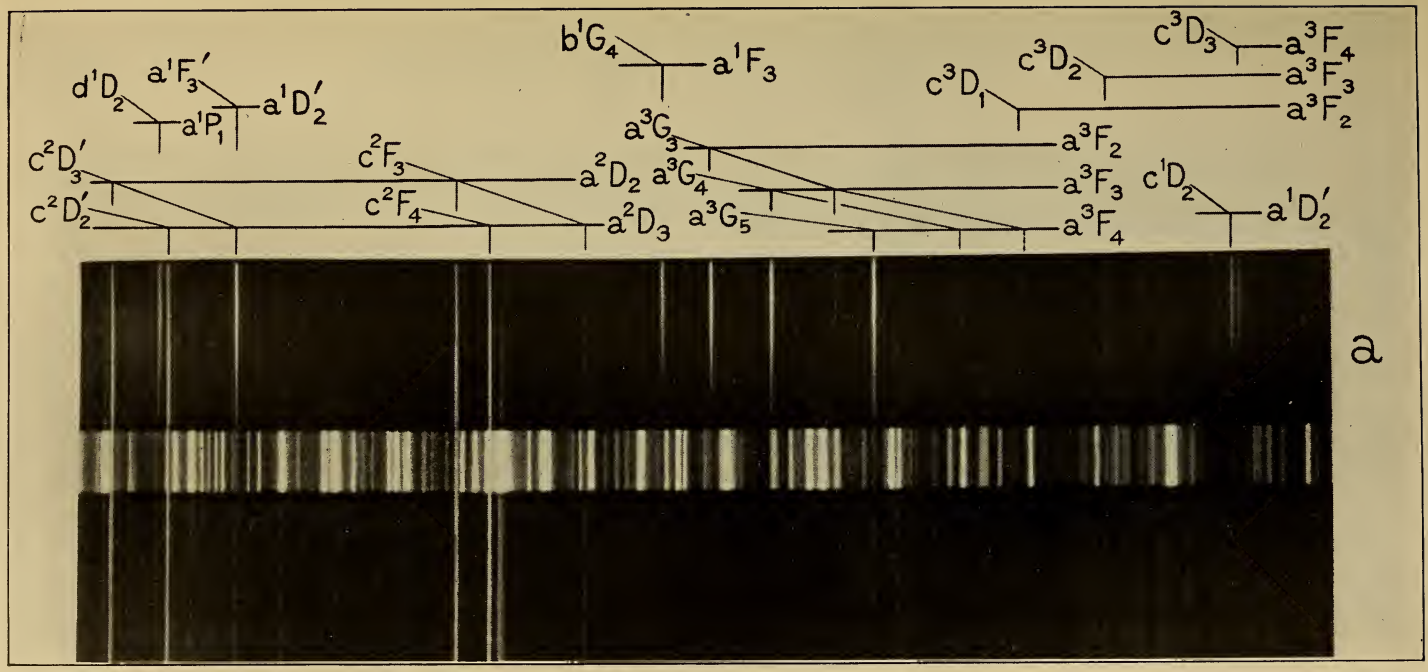


FIG. 4.—*Multiplets in scandium spectra*

a^2D-c^2F, 3,015.35 to 3,030.74 A.
a^2D-c^2D', 2,980.74 and 2,988.75 A. } See p. 348, and Table 6, p. 352
a^3F-a^3G, 3,045.73 to 3,075.38.
a^3F-c^3D, 3,082.57 to 3,108.50. } See p. 331, and Table 3, p. 338

a^1F-a^1G, 3,039.94 A.
$a^1D'-a^1F'$, 2,988.75A.
a^1P-d^1D, 2,979.70 A.
$a^1D'-c^1D$, 3,107.53 A. } See pp. 336, 337, and Table 3, p. 338

Note strong enhancement of the subordinate lines at negative electrode of arc; also coincidence of arc and enhanced line at 2,988.75 A. The lines a^3F-c^3D $a^1D'-c^1D$ are those from which the ionization potential of Sc II was determined

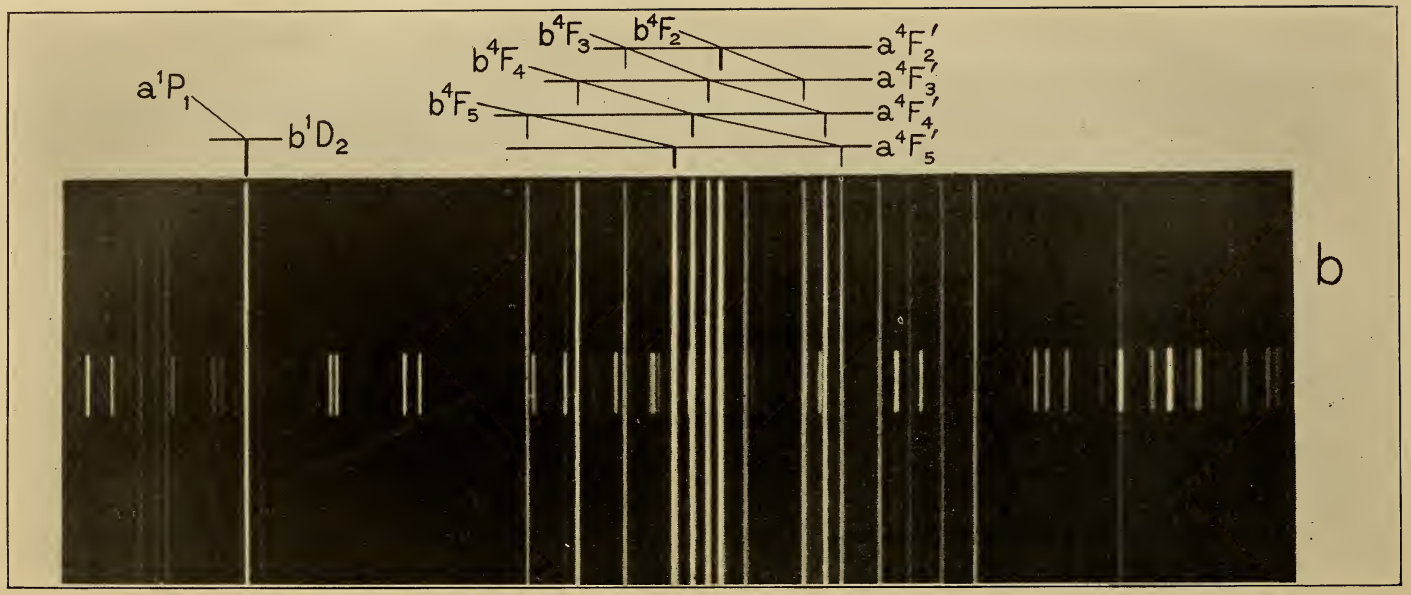


FIG. 5.—*Multiplets in scandium spectra*

$a^4F'-b^4F$, 5,064.31 to 5,101.12 A. See Table 5, p. 346, and Table 6, p. 352
b^1D-a^1P, 5,031.02 A. See Table 2, p. 336, and Table 3, p. 338

TABLE 2.—*Combinations in the Sc II spectrum*—Continued

	b^3D_3	b^3D_2	b^3D_1	c^1D_2	d^1D_2	b^1G_4
				6e	3e	
$a^1D'_2$	(31,662.05)	(31,532.62)		32,170.60	38,284.71	
	4 III A					
a^3F_4	29,902.18					
	1?	3				
a^3F_3	30,140.99	30,011.60				
		0?	3			
a^3F_2		30,170.28	30,107.86			
	3	1				
$a^3D'_3$	29,582.41	29,452.82				
		2				
$a^3D'_2$	(29,722.16)	29,592.83	(29,530.35)			
			1			
$a^3D'_1$		(29,696.25)	29,633.71			
a^3P_2	(27,919.45)					
a^3P_1		(27,871.77)				
a^3P_0			(27,815.24)			
					5e	
a^1P_1		(26,798.29)	(26,735.81)	(27,436.27)	33,550.66	
					1	10 III E
a^1F_3	(24,393.39)	(24,263.94)		(25,901.94)	32,015.96	32,885.85

	$a\ ^3D_3$	$a\ ^3D_2$	$a\ ^3D_1$	$a\ ^1D_2$	$c\ ^3P'_2$	$c\ ^3P'_1$	$c\ ^3P'_0$
	10e	5e	1e		(2e)	(1e)	
$b\ ^3P_2$	39,167.37	39,277.24	39,344.79	(36,803.94)	37,243.58	37,014.96	
		9e	6e		1e	masked	1?
$b\ ^3P_1$		39,046.84	39,114.35	(36,573.52)	37,473.93	(37,245.37)	37,127.96
			8e			1e	
$b\ ^3P_0$			39,001.59			37,358.12	

NOTE.—Other combinations on p. 331.

	$b\ ^1G_4$	$a\ ^1F'_3$	$d\ ^1D_2$	$a\ ^1P'_1$	$b\ ^1S_0$
	10e	2e	1		
$a\ ^1F_3$	32,885.85	27,178.32	32,015.96		
		10e	3e	3e	
$a\ ^1D'_2$		33,446.84	38,284.71	34,318.38	
			5e	2e	4e
$a\ ^1P_1$			33,550.66	29,584.69	34,126.96

Table 3 contains all the lines which have been classified, arranged in order of increasing wave length, and gives both wave lengths and wave numbers. The intensities in the column headed M are from Meggers's estimates in the arc.[12] The letter "e" denotes a line strengthened at the electrode or confined to its vicinity. The columns headed K give the intensity in the arc, and the temperature class, according to King.[13] That headed o–c gives the excess of the observed wave length above that computed from the difference of

[12] B. S. Sci. Paper No. 549.
[13] Ap. J., **54**, pp. 31-36; 1921.

the terms given in Table 1. In a few cases, where the value of one of the terms involved has been determined only from the line in question, the residual is necessarily zero, and is given in parentheses in the table. Only three of these residuals exceed 0.03 A. One of these is for a line measured only by Exner and Haschek, while in another case the identification, and in the third the measures are doubtful. For the remaining 139 lines the average residual, regardless of sign, is ±0.0074 A, corresponding to a probable error of ±0.0063 A. If it is assumed that the residuals recorded as 0.01 really lie between 0.005 and 0.015, and so on, the distribution of the observed residuals and that predicted by the law of errors are as follows.

Residual	−3	−2	−1	0	1	2	3
Observed number	1	7	29	54	36	6	1
Theoretical number	½	7	34	56	34	7	½

Since 53 different energy levels (terms or components of terms) have been determined from these 139 lines, the actual probable error of an observed wave length, assuming, as is probable, that the combination principle is rigorously true, is $0.0063 \times (139/87)^{½}$ or 0.0080 A, which is satisfactorily small.

The only outstanding line of intensity greater than 2 is an isolated one at λ2,273.10 (intensity 3, $n = 43{,}979.16$). This has not been classified.

TABLE 3.—*Classified lines of Scandium II*

λ	o-c	Intensity M	Intensity class K	ν	Origin
2,540.87	+1	1e		39,344.79	$a^3D_1-b^3P_2$
2,545.24	0	5e		39,277.24	$a^3D_2-b^3P_2$
2,552.38	−1	10e		39,167.37	$a^3D_3-b^3P_2$
2,555.84	+1	6e		39,114.35	$a^3D_1-b^3P_1$
2,560.26	−1	9e		39,046.84	$a^3D_2-b^3P_1$
2,563.23	(0)	8e		39,001.59	$a^3D_1-b^3P_0$
2,611.23	+1	3e		38,284.71	$a^1D'_2-d^1D_2$
2,667.73	+1	1e		37,473.93	$b^3P_1-c^3P'_2$
2,676.00	+1	1e		37,358.12	$b^3P_0-c^3P'_1$
2,684.23	−1	2e		37,243.58	$b^3P_2-c^3P'_2$
2,692.59	(0)	1?		37,127.96	$b^3P_1-c^3P'_0$
2,700.81	−1	1e		37,014.96	$b^3P_2-c^3P'_1$
2,724.16	−1	1e?		36,697.71	$a^3D'_1-b^3P'_0$
2,729.60	+2	1e		36,624.58	$a^3D'_2-b^3P'_1$
2,735.61	0	1e	Fe?	36,544.12	$a^3D'_2-b^3P'_2$
2,782.34	−1	3e		35,930.40	$a^3F_2-b^3F'_2$
2,789.20	+1	5e		35,842.02	$a^3F_3-b^3F'_3$
2,794.70	+1	1e		35,771.49	$a^3F_2-b^3F'_2$
2,801.35	0	6e		35,686.58	$a^3F_4-b^3F'_4$
2,807.91	0	1e		35,603.21	$a^3F_4-b^3F'_3$
2,819.56	+1	5e		35,456.11	$a^3D'_1-b^3F'_2$
2,822.17	−1	7e		35,423.32	$a^3D'_2-b^3F'_3$
2,826.69	0	10e		35,366.68	$a^3D'_3-b^3F'_4$
2,827.81	0	2e		35,352.68	$a^3D'_2-b^3F'_2$
2,833.36	−1	1e		35,283.43	$a^3D'_3-b^3F'_3$

TABLE 3.—*Classified lines of Scandium II*—Continued

λ	o–c	Intensity M	Intensity class K	ν	Origin
2,859.32	−1	2e		34,963.11	$a^3P_1-b^3P'_2$
2,863.67	−1	2e		34,910.00	$a^3P_0-b^3P'_1$
2,864.15	−2	1e		34,904.15	$a^3P_1-b^3P'_1$
2,866.04	+1	4e		34,881.13	$a^3P_2-b^3P'_2$
2,866.71	+1	2e		34,872.98	$a^3P_1-b^3P'_0$
2,870.90	+1	2e		34,822.09	$a^3P_2-b^3P'_1$
2,913.04	+3	3e		34,318.38	$a^1D'_2-a^1P'_1$
2,929.38	+(0)	4e		34,126.96	$a^1P_1-b^1S_0$
2,949.92	+1	1		33,889.35	$a^1P_1-b^3P'_2$
2,979.70	−2	5e		33,550.66	$a^1P_1-d^1D_2$
2,988.95	+1	10e		33,446.84	$a^1D'_2-a^1F'_3$
3,039.94	+(0)	10e		32,885.85	$a^1F_3-b^1G_4$
3,045.73	0	15e		32,823.33	$a^3F_2-a^3G_3$
3,052.92	−2	20e		32,746.03	$a^3F_3-a^3G_4$
3,060.53	0	3e		32,664.61	$a^3F_3-a^3G_3$
3,065.11	+(0)	30e		32,615.80	$a^3F_4-a^3G_5$
3,075.38	+2	3e		32,506.89	$a^3F_4-a^3G_4$
3,082.57	+1	2e		32,431.07	$a^3F_2-c^3D_1$
3,092.52	+1	2e		32,326.72	$a^3F_3-c^3D_2$
3,107.39	+3	1		32,172.04	$a^3D_3-a^1F_3$
3,107.53	+(0)	6e		32,170.60	$a^1D'_2-c^1D_2$
3,108.50	−1	3e		32,160.56	$a^3F_4-c^3D_3$
3,122.54	+2	1		32,015.96	$a^1F_3-d^1D_2$
3,122.98	−1	3e		32,011.45	$a^3D'_1-c^3D_2$
3,126.02	+1	1		31,980.32	$a^3D'_2-c^3D_3$
3,128.29	0	5e		31,957.11	$a^3D'_1-c^3D_1$
3,133.12	+1	8e		31,907.85	$a^3D'_2-c^3D_2$
3,138.46	0	1e?		31,853.57	$a^3D'_2-c^3D_1$
3,139.76	+2	10e		31,840.37	$a^3D'_3-c^3D_3$
3,146.91	+1	1		31,768.03	$a^3D'_3-c^3D_2$
3,170.40	−1	1		31,532.67	$a^1D'_2-b^3D_2$
3,190.41	0	2e		31,334.90	$a^3P_0-a^3S_1$
3,191.01	0	5e		31,329.01	$a^3P_1-a^3S_1$
3,199.38	+1	10e		31,247.06	$a^3P_2-a^3S_1$
3,251.31	0	3	1 IV	30,747.99	$a^3D_2-a^1P_1$
3,311.73	+1	3		30,187.04	$a^3P_1-c^3D_2$
3,312.75	−1	5	Nd?	30,177.74	$a^3P_2-c^3D_3$
3,313.57	0	0?		30,170.28	$a^3F_2-b^3D_2$
3,316.79	+1	1?		30,140.99	$a^3F_3-b^3D_3$
3,317.06	+1	0	Dy?	30,138.52	$a^3P_0-c^3D_1$
3,317.70	+1	1		30,132.72	$a^3P_1-c^3D_1$
3,320.44	−1	3		30,107.86	$a^3F_2-b^3D_1$
3,320.72	−1	1?		30,105.33	$a^3P_2-c^3D_2$
3,331.09	0	3		30,011.60	$a^3F_3-b^3D_2$
3,343.28	0	4	1 III A	29,902.18	$a^3F_4-b^3D_3$
3,352.05	0	3	2 IV	29,823.95	$a^3D_1-a^3P_2$
3,353.73	0	25	10 III	29,809.01	$a^1D_2-a^1F_3$
3,359.68	0	10	6 III	29,756.22	$a^3D_2-a^3P_2$
3,361.26	−1	10	6 III	29,742.23	$a^3D_1-a^3P_1$
3,361.94	0	12	6 III	29,736.22	$a^3D_1-a^3P_0$
3,363.52	−1	1		29,722.25	$a^3D'_2-b^3D_3$
3,366.46	0	1		29,696.30	$a^3D'_1-b^3D_2$
3,368.94	0	15	8 III	29,674.43	$a^3D_2-a^3P_1$
3,372.14	0	20	12 III	29,646.27	$a^3D_3-a^3P_2$
3,373.57	+1	1?		29,633.71	$a^3D'_1-b^3D_1$
3,378.23	−1	2		29,592.83	$a^3D'_2-b^3D_2$
3,379.19	−1	2e		29,584.42	$a^1P_1-a^1P'_1$
3,379.42	−1	3		29,582.41	$a^3D'_3-b^3D_3$
3,394.29	+1	1		29,452.82	$a^3D'_3-b^3D_2$
3,535.73	0	10	6 III	28,274.65	$a^1D_2-a^1P_1$
3,558.55	0	20	7 II	28,093.34	$a^3D_2-a^3D'_3$
3,567.70	−1	20	6 II	28,021.29	$a^3D_1-a^3D'_2$
3,572.53	0	50	20 II	27,983.41	$a^3D_3-a^3D'_3$
3,576.35	0	35	8 II	27,953.52	$a^3D_2-a^3D'_2$
3,580.94	0	30	7 II	27,917.69	$a^3D_1-a^3D'_1$

TABLE 3.—*Classified lines of Scandium II*—Continued

λ	o–c	Intensity M	Intensity class K	ν	Origin
3, 589. 64	0	20	6 II	27, 850. 03	$a^3D_2-a^3D'_1$
3, 590. 48	+1	20	6 II	27, 843. 51	$a^3D_3-a^3D'_2$
3, 613. 84	0	60	30 II	27, 663. 54	$a^3D_3-a^3F_4$
3, 630. 76	0	50	12 II	27, 534. 62	$a^3D_2-a^3F_3$
3, 642. 79	0	40	25 II	27, 443. 69	$a^3D_1-a^3F_2$
3, 645. 31	0	30	10 III	27, 424. 72	$a^3D_3-a^3F_3$
3, 651. 80	0	25	7 III	27, 375. 98	$a^3D_2-a^3F_2$
3, 664. 25	0	1		27, 282. 97	$a^1D_2-a^3F_2$
3, 666. 54	+1	3	2 III	27, 265. 93	$a^3D_3-a^3F_3$
3, 675. 26	−1	1		27, 201. 24	$a^1D_2-a^3P_1$
3, 678. 36	−1	2e		27, 178. 32	$a^1F_3-a^1F'_3$
3, 833. 08	0	3		26, 081. 31	$a^3D_1-a^1D'_2$
3, 843. 06	+1	4		26, 013. 58	$a^3D_2-a^1D'_2$
3, 923. 51	+1	2		25, 480. 19	$a^1D_2-a^3D'_2$
3, 989. 06	+1	2		25, 061. 50	$a^1D_2-a^3F_3$
4, 014. 49	−1	5	5 IV E	24, 902. 75	$a^1D_2-a^3F_2$
4, 246. 83	0	100	75 III E	23, 540. 37	$a^1D_2-a^1D'_2$
4, 279. 95	+1	1		23, 358. 21	$a^3F'_2-a^3D'_3$
4, 294. 77	0	8	10 IV E	23, 277. 61	$a^3F'_3-a^3D'_3$
4, 305. 71	0	10	10 IV E	23, 218. 46	$a^3F'_2-a^3D'_2$
4, 314. 09	0	60	100 III E	23, 173. 37	$a^3F'_4-a^3D'_3$
4, 320. 73	+1	50	75 III E	23, 137. 75	$a^3F'_3-a^3D'_2$
4, 325. 00	+1	40	50 III E	23, 114. 91	$a^3F'_2-a^3D'_1$
4, 354. 60	−1	5	8 V E	22, 957. 79	$a^3F'_3-a^3F_4$
4, 374. 46	−1	40	60 III E	22, 853. 56	$a^3F'_4-a^3F_4$
4, 384. 80	−2	6	8 IV E?	22, 799. 67	$a^3F'_2-a^3F_3$
4, 400. 38	−1	30	50 III E	22, 718. 95	$a^3F'_3-a^3F_3$
4, 415. 55	0	20	40 III E	22, 640. 90	$a^3F'_2-a^3F_2$
4, 420. 66	−1	2		22, 614. 72	$a^3F'_4-a^3F_3$
4, 431. 35	+1	3	4 V E	22, 560. 17	$a^3F'_3-a^3F_2$
4, 670. 40	0	15	15 IV E	21, 405. 47	$b^1D_2-a^1F_3$
4, 698. 30	+5	2	(E & H)	21, 278. 36	$a^3F'_2-a^1D'_2$
5, 031. 02	0	40	10 V E	19, 871. 16	$b^1D_2-a^1P_1$
5, 239. 81	−2	15	2 IV E	19, 079. 36	$a^1S_0-a^1P_1$
5, 318. 35	+1	3	1 IV E	18, 797. 60	$b^1D_2-a^3P_1$
5, 334. 22	−1	2	tr IV A	18, 741. 68	$a^3P'_0-a^1P_1$??
5, 357. 18	−2	2		18, 661. 36	$a^3P'_2-a^1P_1$
5, 526. 82	(0)	75	10 V E	18, 088. 58	$a^1G_4-a^1F_3$?
5, 552. 25	+1	3		18, 005. 73	$a^1S_0-a^3P_1$
5, 640. 99	0	15	2 V E	17, 722. 48	$a^3P'_1-a^3P_2$
5, 657. 89	+1	25	15 V E	17, 669. 54	$a^3P'_2-a^3P_2$
5, 658. 35	0	8	2 V E	17, 668. 11	$a^3P'_0-a^3P_1$
5, 667. 16	+1	10	2 V E	17, 640. 64	$a^3P'_1-a^3P_1$
5, 669. 05	0	12	2 IV E	17, 634. 76	$a^3P'_1-a^3P_0$
5, 684. 21	+2	15	8 V E	17, 587. 73	$a^3P'_2-a^3P_1$
6, 245. 64	+2	20	8 V E	16, 006. 75	$a^3P'_2-a^3D'_3$
6, 279. 74	−3	15		15, 919. 83	$a^3P'_1-a^3D'_2$
6, 300. 70	0	6		15, 866. 87	$a^3P'_2-a^3D'_2$
6, 309. 90	−2	15		15, 843. 74	$a^3P'_0-a^3D'_1$
6, 320. 86	−1	7		15, 816. 27	$a^3P'_1-a^3D'_1$
6, 342. 08	0	1		15, 763. 34	$a^3P'_2-a^3D'_1$
6, 604. 60	+1	10		15, 136. 79	$b^1D_2-a^1D'_2$

III. THE ARC SPECTRUM (Sc I)

The normal state of the neutral atom evidently corresponds to a ^2D term, of separation 168. Transitions between this and higher terms account for all of the numerous lines which King has found to be strong in the furnace at low temperatures. The next lowest level, as has already been said, is a $^4F'$ term, which combines with a triad $^4D'$, ^4F, $^4G'$, to give strong multiplets in the green and yellow.

These terms account for the strongest lines, but leave the majority unidentified.

Further study revealed the existence of a $^2F'$ term, which accounts for some prominent lines in the green, a second ^2D, about 17,000 above the first, and a ^2G term lying a little higher, and of several terms at a much higher level which combine with a number of the terms already identified by their combinations with the low ^2D term. The latter terms were at first puzzling. The three lowest are close together, and had all been classed as $^2D'$ terms, an unprecedented situation, hardly reconcilable with the theory of Hund, who has expressed the opinion [14] that some of the lines must be intercombinations. This anticipation has been found to be correct. There is only one $^2D'$ term in this neighborhood, composed of parts of what were previously supposed to be two different $^2D'$ terms. The other levels are components of $^4D'$ and ^4F terms. When the remaining components of these terms were found, it appeared that combinations of these terms, and of a $^4P'$ term, which completes the triad, with numerous still higher terms accounted for more than 100 lines, including almost all those of any strength which had not previously been identified.

The quartet system was thus greatly extended, but remained in two distinct parts, one comprising the low $^4F'$ term, the triad $^4D'$, ^4F, $^4G'$, and a higher $^4F'$ term, and the other the more extensive group just described, with no recognizable combinations between the two. This difficulty was resolved through the kindness of Doctor King, who in answer to a request, forwarded positives of his original arc and furnace spectra. On examination of these, a number of new low-temperature lines were found in the red, which had not been recorded as scandium lines by Doctor King on account of their absence from all previously published lists, but which agreed exactly with the predicted positions of all the other intercombinations between the low ^2D term and the ^4P, $^4D'$, ^4F triad which are permitted by the inner quantum rule. Further search revealed some faint lines in the ultra-violet, greatly strengthened in the furnace spectrum, and measurable only there, which proved to be combinations between the low ^2D and the $^4G'$ and ^4F terms of the other triad. This gave the levels of these terms, and of the low $^4F'$ which combines with them. With this aid, another combination between the two parts of the quartet system was found in the deep red, and the apparent absence of others was explained by finding that they would lie far in the infra-red. A number of high terms of the doublet system have also been found. Their combinations with the terms of the middle

[14] Linienspektren und Periodisches System der Elemente (Berlin, 1927). The greater part of this book was courteously shown to one of us (H. N. R.) in proof.

set indicate that the remarkable term at 24,656, which is evidently a doublet with its components too close to be resolved, is a P term.

Hund's theory predicts the existence of certain low terms in addition to those so far described, of types $^4P'$, $^2P'$, and ^2S. Combinations

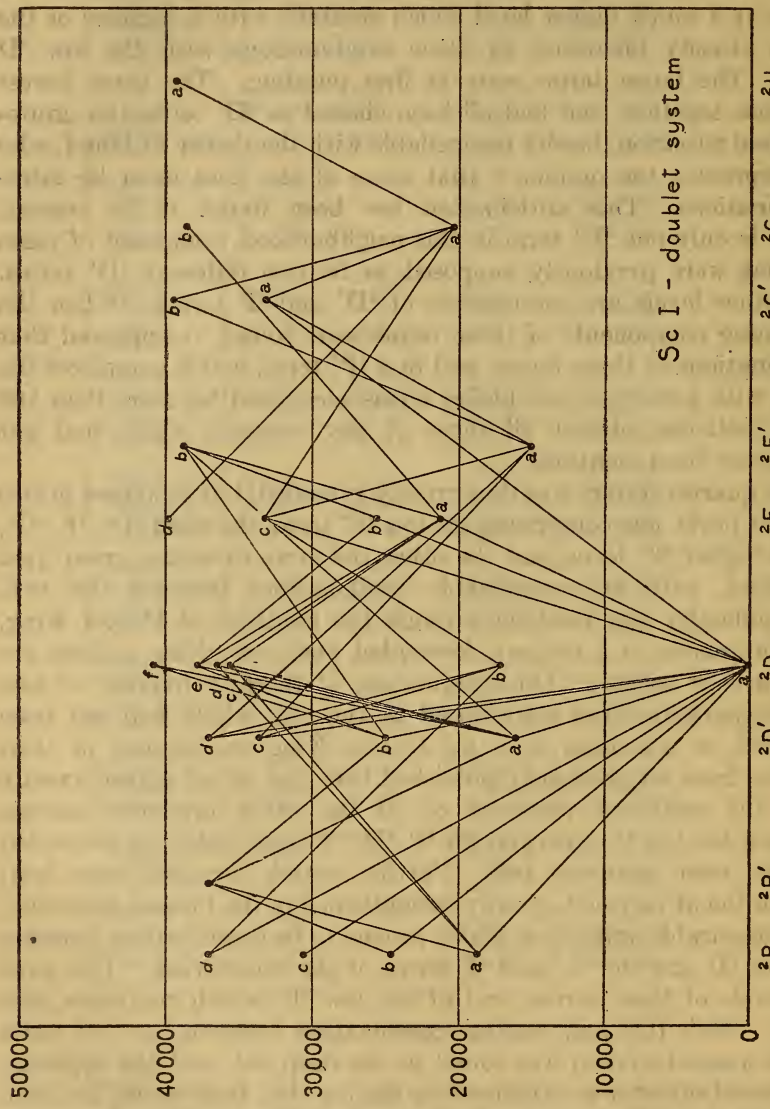


Fig. 2.—*Energy diagram for the Sc I spectrum. Doublet system terms and combinations*

of the first of these with ^4P and $^4S'$ terms have been identified, but nothing has been found which serves to connect these with the main part of the quartet system, and the absolute energy levels of these terms remain unknown. The identification of this term is certain; that of certain other lines, which probably represent combinations

involving the $^2P'$, term, can not be regarded as conclusive. It could best be tested by observations of the Zeeman effect, or, perhaps, by analogy with the spectrum of yttrium, which is very similar to that of scandium.

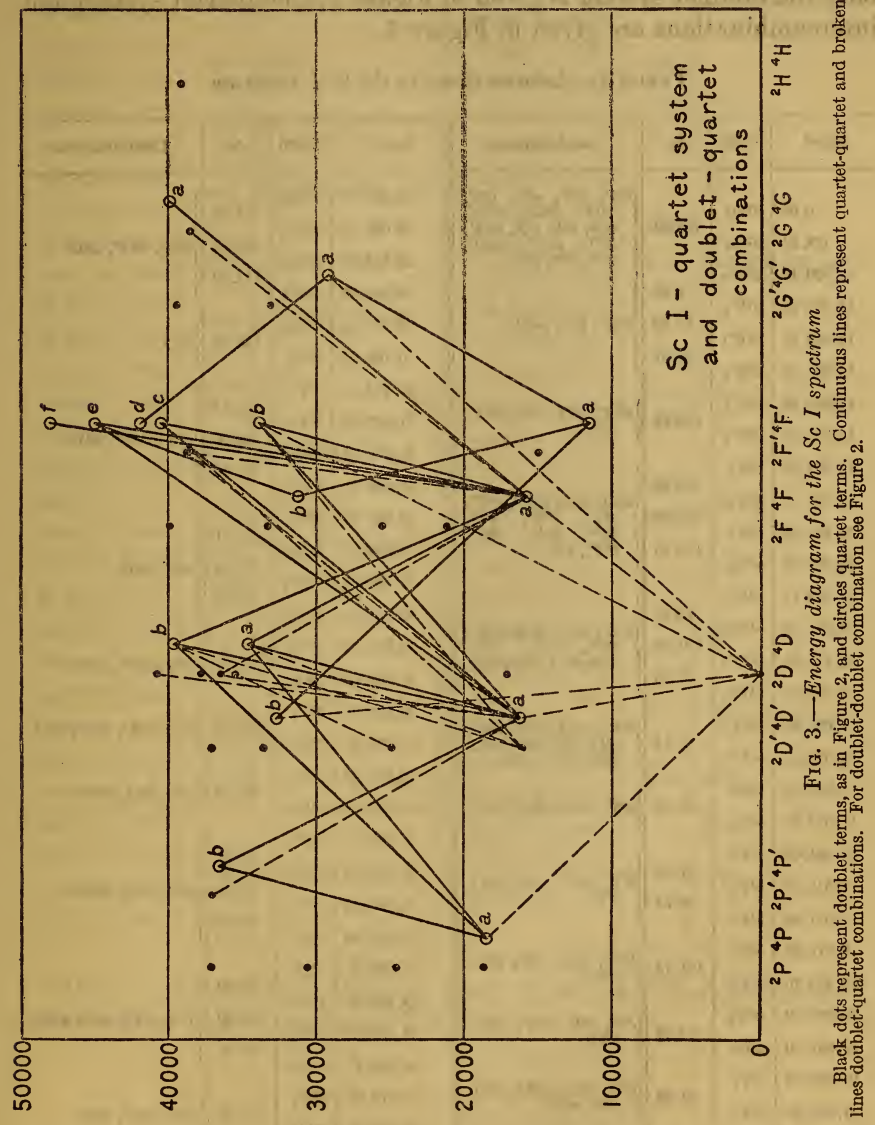


FIG. 3.—*Energy diagram for the Sc I spectrum*

Black dots represent doublet terms, as in Figure 2, and circles quartet terms. Continuous lines represent quartet-quartet and broken lines doublet-quartet combinations. For doublet-doublet combination see Figure 2.

Table 4, which is arranged similarly to Table 1, gives the terms which have been identified in the arc spectrum. For the $^4P'$ and the probable $^2P'$ terms, and those which combine with them, which are listed at the end, the energy levels are referred to the lowest components of these themselves, and unknown quantities, denoted by

x and y in the table, must be added to reduce them to the system employed for the rest.

The connected terms for the Sc I spectrum are shown diagrammatically in Figures 2 and 3. In order to simplify the representation only the doublet system is given in Figure 2; the quartet system and intercombinations are given in Figure 3.

TABLE 4.—*Relative terms in the Sc I spectrum*

Level	Term	Δν	Combinations	Level	Term	Δν	Combinations
0.00	a^2D_2	168.34	a^2P, b^2P, c^2P, d^2P, a^2D', b^2D', c^2D', a^2F, b^2F, c^2F, a^2G', a^4P, a^4D', b^4D', a^4F, b^4F, a^4G'.	29,022.87	$a^4G'_3$	73.33	a^4F', d^4F', a^2D.
168.34	a^2D_3			29,096.20	$a^4G'_4$	93.63	
11,520.15	$a^4F'_2$	37.49		29,189.83	$a^4G'_5$	113.69	
11,557.64	$a^4F'_3$	52.60	b^4D', b^4F, a^4G'.	29,303.52	$a^4G'_6$		
11,610.24	$a^4F'_4$	67.07		30,573.10	c^2P_1	133.51	a^2D.
11,677.31	$a^4F'_5$			30,706.61	c^2P_2		
14,926.24	$a^2F'_3$	115.74	c^2D', d^2D', c^2F, a^2G', b^2G'.	31,172.62	b^4F_2	43.14	a^4F', e^4F', a^2D.
15,041.98	$a^2F'_4$			31,215.76	b^4F_3	59.56	
15,672.55	a^4F_2	83.96	a^4D, b^4D, b^4F', c^4F', e^4F', f^4F', a^4G, b^2P', a^2D, d^2D, b^2F', b^2G.	31,275.32	b^4F_4	75.49	
15,756.51	a^4F_3	125.25		31,350.81	b^4F_5		
15,881.76	a^4F_4	144.76		32,637.40	$b^4D'_1$	21.81	a^4F' a^2D.
16,026.52	a^4F_5			32,659.21	$b^4D'_2$	37.63	
16,009.71	$a^4D'_1$	12.07	b^4P', a^4D, b^4D, b^4F', c^4F', e^4F', b^2P', a^2D, d^2D, f^2D, b^2F'.	32,696.84	$b^4D'_3$	54.70	
16,021.78	$a^4D'_2$	119.26		32,751.54	$b^4D'_4$		
16,141.04	$a^4D'_3$	69.76		33,056.19	$a^2G'_4$	95.21	a^2D, a^2F', a^2G.
16,210.80	$a^4D'_4$			33,151.40	$a^2G'_5$		
16,096.86	$a^2D'_2$	−74.14	b^2P', a^2D, c^2D, d^2D, e^2D, f^2D, b^2F', a^4D, b^4D, b^4F', c^4F'.	33,154.01	c^2F_3	124.63	a^2D, b^2D, a^2F', a^2G.
16,022.72	$a^2D'_3$			33,278.64	c^2F_4		
17,025.36	b^2D_2	−12.38	d^2P, c^2D', d^2D', c^2F.	33,615.06	$c^2D'_2$	92.19	a^2D, b^2D, a^2F'.
17,012.98	b^2D_3			33,707.25	$c^2D'_3$		
18,504.05	a^4P_1	11.72	b^4P', c^4P'?, a^4D, b^4D, a^2D.	33,763.57	$b^4F'_2$	35.11	a^4D', a^4F, a^2D'.
18,515.77	a^4P_2	55.63		33,798.68	$b^4F'_3$	47.94	
18,571.40	a^4P_3			33,846.62	$b^4F'_4$	59.78	
18,711.03	a^2P_1	144.73	b^2P', a^2D, c^2D, d^2D, c^4P'?	33,906.40	$b^4F'_5$		
18,855.76	a^2P_2			34,390.25	a^4D_1	32.60	a^4P, a^4D', a^4F, a^2D'.
20,239.92	a^2G_4	−2.82	c^2F, d^2F, a^2G', b^2G', a^2H.	34,422.85	a^4D_2	57.20	
20,237.10	a^2G_5			34,480.05	a^4D_3	87.05	
21,032.78	a^2F_3	53.06	a^2D, c^2D, d^2D, e^2D, b^2F', c^4F'.	34,567.10	a^4D_4		
21,085.84	a^2F_4			35,671.00	c^2D_2	74.57	a^2P, a^2D', a^2F.
24,656.80	$b^2P_{2,1}$	0.00	b^2P', a^2D, c^2D.	35,745.57	c^2D_3		
24,866.18	$b^2D'_2$	147.97	b^2P', a^2D, e^2D, f^2D, b^2F', b^4D.	36,276.76	d^2D_2	53.73	a^2P, a^2D', a^2F, a^4D', a^4F.
25,014.15	$b^2D'_3$			36,330.49	d^2D_3		
25,584.64	b^2F_3	140.08	a^2D, e^2D, b^2F', b^2G.	36,492.82	$b^4P'_1$	22.94	a^4P, a^4D'.
25,724.72	b^2F_4			36,515.76	$b^4P'_2$	57.04	
				36,572.80	$b^4P'_3$		

TABLE 4.—*Relative terms in the Sc I spectrum*—Continued

Level	Term	Δν	Combinations	Level	Term	Δν	Combinations
36,934.15	$d^2D'_2$	105.62	a^2D, b^2D, a^2F'.	40,802.72	f^2D_2	22.93	a^2D', b^2D', a^4D'.
37,039.77	$d^2D'_3$			40,825.65	f^2D_3		
37,125.72	d^2P_1	−39.41	a^2D, b^2D.	41,921.94	$d^4F'_2$	38.92	a^4G'.
37,086.31	d^2P_2			41,960.86	$d^4F'_3$	54.71	
37,085.72	$b^2P'_1$	62.53	a^2P, b^2P, a^2D', b^2D', a^4D', a^4F.	42,015.57	$d^4F'_4$	69.44	
37,148.25	$b^2P'_2$			42,085.01	$d^4F'_5$		
37,780.83	e^2D_2	74.67	b^2P, a^2D', b^2D', a^2F, b^2F.	44,598.80	c^4D_4	?	a^4F
37,855.50	e^2D_3			44,823.06	$e^4F'_2$	86.44	a^4D', a^4F, b^4F, a^4F.
38,571.70	b^2G_4	86.53	b^2F, a^4F.	44,909.50	$e^4F'_3$	106.87	
38,658.23	b^2G^5			45,016.37	$e^4F'_4$	109.20	
38,871.60	$b^2F'_3$	87.56	a^2D', b^2D', a^2F, b^2F, a^4D', a^4F.	45,125.57	$e^4F'_5$		
38,959.16	$b^2F'_4$			47,898.95	f^4F_2	47.30	a^4F.
39,153.42	a^2H_5	95.85	a^2G.	47,946.25	f^4F_3	125.52	
39,249.27	a^2H_6			48,071.77	f^4F_4	251.81?	
39,392.95	$b^2G'_4$	30.78	a^2F', a^2G.	48,323.58	f^4F_5?		
39,423.73	$b^2G'_5$			x	$a^4P'_1$	29.03	a^4S', b^4P.
39,701.30	b^4D_1	20.41	a^4P, a^4D', a^4F, a^2D', b^2D'.	$x+29.03$	$a^4P'_2$	52.02	
39,721.71	b^4D^2	33.22		$x+81.05$	$a^4P'_3$		
39,754.93	b^4D_3	44.92		$x+20,260.88$	$a^4S'_2$		a^4P'
39,799.85	b^4D_4			$x+20,651.73$	b^4P_1	30.75	a^4P'
39,881.25	d^2F_3	7.86	a^2G.	$x+20,682.48$	b^4P_2	56.34	
39,889.11	d^2F_4			$x+20,738.82$	b^4P_3		
39,861.25	a^4G_3	41.40	a^4F_5.	y	$a^2P'_1$	80.40	x^2D', a^2S', y^2D'.
39,902.65	a^4G_4	55.06		$y+80.40$	$a^2P'_2$		
39,957.71	a^4G_5	70.52		$y+21,766.52$	$x^2D'_2$	54.22	a^2P'.
40,028.23	a^4G_6			$y+21,820.74$	$x^2D'_3$		
40,521.21	$c^4F'_2$	33.77	a^4D', a^4F, a^2D'.	$y+21,937.03$	$a^2S'_1$		a^2P'.
40,554.98	$c^4F'_3$	49.04		$y+29,831.50$	$y^2D'_2$	98.04	a^2P'.
40,604.02	$c^4F'_4$			$y+29,929.54$	$y^2D'_3$		
40,670.87	$c^4F'_5$	66.85					

Table 5 exhibits the multiplets which have been identified in Sc I and is similar in all respects to Table 2.

TABLE 5.—*Combinations in the Sc I spectrum*

	a^2D_3	a^2D_2	c^2D_3	c^2D_2	d^2D_3	d^2D_2	$b^2P'_2$	$b^2P'_1$
a^4F_5								
	1 I A							
a^4F_4	15,713.30		(19,863.81)		(20,448.73)			
	10 I A	3 II A			0 IV A			
a^4F_3	15,588.12	15,756.49	(19,989.11)	(19,914.54)	20,573.92	(20,520.20)	(21,381.79)	
	2 II A	8 I A						
a^4F_2	15,504.17	15,672.53		(19,998.49)	(20,657.98)	(20,604.24)	(21,475.74)	(21,413.21)
	2 I A							
$a^4D'_4$	16,042.40		(19,531.77)		(20,119.69)			
	20 I A	2 II A			1 IV A		1 III A	
$a^4D'_3$	15,972.65	16,141,09	(19,604.53)	(19,529.96)	20,189.55	(20,135.72)	21,007.36	
	10 I A	15 I A				2 III A		1 IV A
$a^4D'_2$	15,853.54	16,021.78		(19,649.18)	(20,308.67)	20,254.71	(21,126.43)	21,063.84
		1 I A						
$a^4D'_1$		16,009.65				(20,267.05)		(21,076.01)
	1 I A	2 I A						
a^4P_3	18,403.10	18,571.57	(17,174.10)	(17,099.53)	(17,759.02)	(17,705.29)	(18,576.78)	
	5 I A	3 I A						
a^4P_2	18,347.45	18,515.64	(17,229.70)	(17,155.30)	(17,814.70)	(17,760.97)	(18,632.46)	(18,569.93)
		5 I A						
a^4P_1		18,504.06		(17,166.90)		(17,772.66)		(18,581.62)
	40 I A	8 II A	5 III		4 III A		2 IV A	
$a^2D'_3$	15,854.34	16,022.76	19,722.86	(19,648.28)	20,307.82	(20,254.04)	21,125.48	
	9 II A	30 I A		1		15 III A	1 IV A	1 IV A
$a^2D'_2$	15,928.56	16,096.85	(19,648.71)	19,574.11	(20,233.63)	20,179.84	21,051.33	20,988.79
	7 II A	4 II A	5 IV A		1 IV		3 IV A	
a^2P_2	18,687.42	18,855.79	16,889.76	(16,815.24)	17,474.78	(17,419.00)	18,292.52	(18,229.94)
		9 II A		3 IV		0 IV		
a^2P_1		18,711.03		16,959.90		17,565.72	(18,437.22)	(18,374.69)
	20 I A		20		3 IV			
a^2F_4	20,917.52		14,659.77		15,244.65			
	5 I A	12 I A		15		2 IV		
a^2F_3	20,864.48	21,032.77	(14,712.79)	14,638.29	(15,297.71)	15,244.23		
	30 I	20 I					2	1
$b^2P_{2,1}$	24,488.51	24,656.77					12,491.46	12,429.04
	70 II	15 I					1	
$b^2D'_3$	24,845.81	25,014.16					12,133.99	
	10 I	50 II						
$b^2D'_2$	24,697.89	24,866.14						(12,219.54)
	60 II							
b^2F_4	25,556.40							
	10 II	40 II						
b^2F_3	25,416.32	25,584.65						

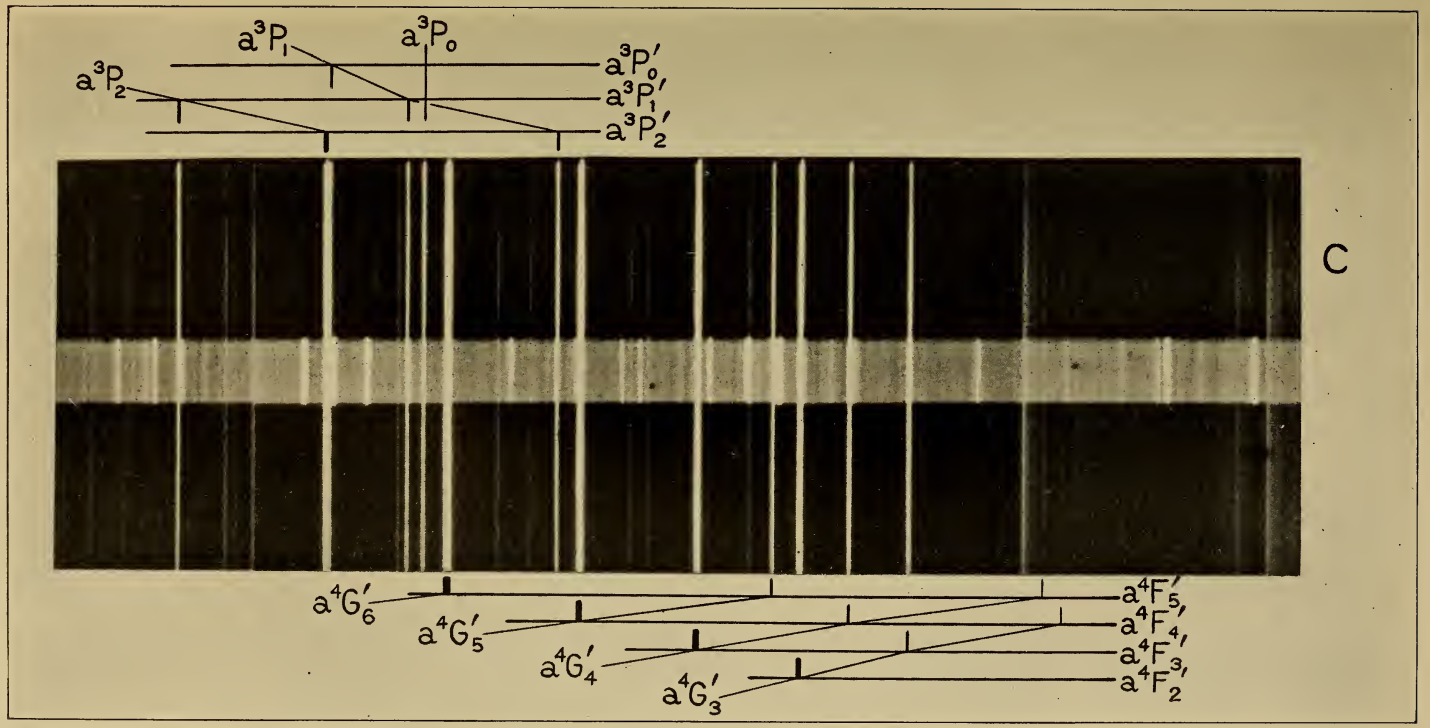


FIG. 6.—*Multiplets in scandium spectra*

$a^3P'-a^3P$, 5,640.99 to 5,684.21 A. See Table 2, p. 336, and Table 3, p. 338
$a^4F'-a^4G'$, 5,671.80 to 5,741.36 A. See Table 5, p. 346, and Table 6, p. 352

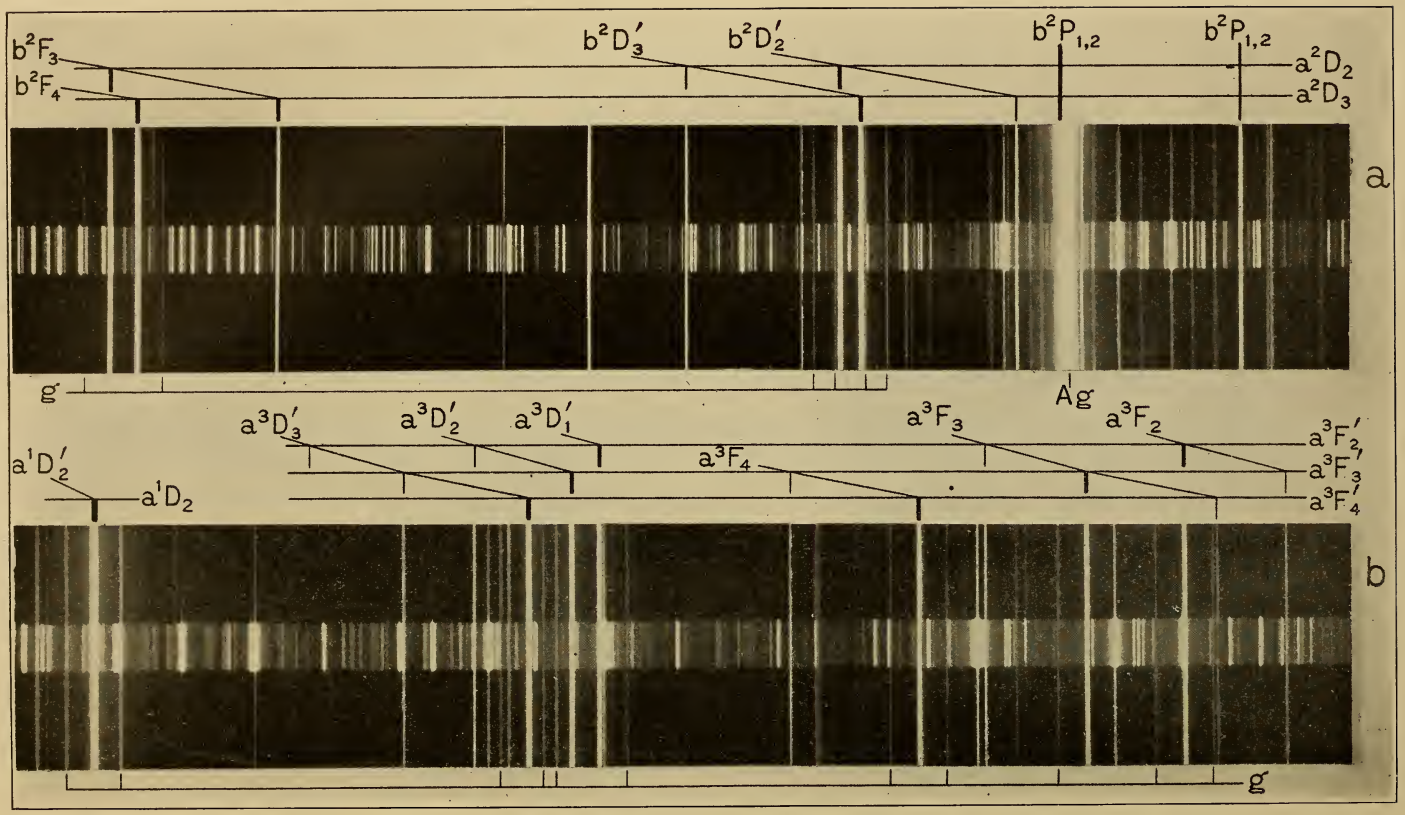


FIG. 7.—*Multiplets in scandium spectra*

(*a*) a^2D-b^2F, 3,907.49 to 3,933.37 A. See Table 5, p. 346, and Table 6, p. 352
a^2D-b^2D', 3,996.61 to 4,047.79 A. See Table 5, p. 346, and Table 6, p. 352
a^2D-b^2P, 4,054.54 to 4,082.40 A. See Table 5, p. 346, and Table 6, p. 352
(*b*) a^1D-a^1D', 4,246.83 A. See Table 2, p. 336, and Table 3, p. 338
$a^3F'-a^3D'$, 4,279.95 to 4,325.00 A. See Table 2, p. 336, and Table 3, p. 338
$a^3F'-a^3F$, 4,354.60 to 4,431.35 A. See Table 2, p, 336, and Table 3, p. 338

Ag, strong silver line, 4,055.25 A
g, pairs of faint lines symmetrically located about intense lines are examples of the so-called Rowland ghosts

TABLE 5.—*Combinations in the Sc I spectrum*—Continued

	e^2D_3	e^2D_2	$b^2F'_4$	$b^2F'_3$	b^2G_5	b^2G_4	f^2D_3	f^2D_2
a^4F_5			(22, 932. 61)		(22, 631. 71)			
				1 IV A				
a^4F_4	(21, 973. 74)		(23, 077. 40)	22, 989. 83	(22, 776. 47)	(22, 690. 04)	(24, 943. 89)	
						1		
a^4F_3	(22, 099. 04)	(22, 024. 36)	(23, 202. 70)	(23, 015. 14)		22, 815. 02	(25, 069. 19)	(25, 046. 16)
a^4F_2	(22, 182. 99)	(22, 108. 32)		(23, 199. 09)			(25, 153. 13)	(25, 130. 21)
$a^4D'_4$	(21, 644. 70)		(22, 748. 36)	(22, 660. 80)			(24, 614. 85)	
			1 III A				2 III A	
$a^4D'_3$	(21, 714. 46)	(21, 639. 79)	22, 818. 20	(22, 730. 56)			24, 684. 71	(24, 661. 70)
				1 III A				1 III A
$a^4D'_2$	(21, 832. 98)	(21, 758. 01)		22, 849. 80			(24, 803. 83)	24, 780. 90
$a^4D'_1$		(21, 771. 11)						(24, 793. 01)
a^4P_3	(19, 284. 03)	(19, 209. 36)						
a^4P_2	(19, 339. 71)	(19, 265. 06)						
a^4P_1		(19, 276. 73)						
	1 IV A		2 III A				3	
$a^2D'_3$	21, 832. 82	(21, 758. 11)	22, 936. 51	(22, 848. 88)			24, 802. 78	(24, 780. 00)
		0		2 IV A				3 III A
$a^2D'_2$	(21, 758. 64)	21, 683. 99		22, 774. 74			(24, 737. 79)	24, 705. 88
a^2P_2	(18, 999. 74)	(18, 925. 07)					(21, 969. 89)	
a^2P_1		(19, 069. 80)						(22, 091. 69)
	4 IV		5					
a^2F_4	16, 769. 69		17, 873. 30	(17, 785. 76)	(17, 572. 41)		(19, 739. 81)	
		5 IV		3 IV				
a^2F_3	(16, 822. 76)	16, 748. 06	(17, 926. 38)	17, 838. 85		(17, 539. 02)		(19, 769. 94)
	7	5						
$b^2P_{2,1}$	13, 198. 67	13, 124. 15					(16, 168. 85)	(16, 145. 92)
	6	1	8				2	
$b^2D'_3$	12, 841. 40	12, 766. 61	13, 944. 85	(13, 857. 45)			15, 811. 56	(15, 788. 57)
		20		6				0 IV
$b^2D'_2$	(12, 989. 32)	12, 914. 34		14, 005. 42			(15, 909. 47)	15, 936. 53
	4		6		7			
b^2F_4	12, 130. 93		13, 234. 45	(13, 146. 88)	12, 933. 51	(12, 846. 98)	(15, 100. 93)	
		3		7		10		
b^2F_3	(12, 270. 56)	12, 196. 26	(13, 374. 52)	13, 286. 96		12, 987. 23		(15, 218. 06)

TABLE 5.—*Combinations in the Sc I spectrum*—Continued

	a^2D_3	a^2D_2	b^2D_3	b^2D_2	$a^2F'_4$	$a^2F'_3$	a^2G_5	a^2G_4
	15 II A	4 I A	3					
c^2P_2	30, 538. 27	30, 706. 63	13, 693. 64					
		10 II A						
c^2P_1		30, 573. 10		(13, 547. 26)				
					50 III		20	
$a^2G'_5$					18, 109. 28		12, 914. 34	(12, 911. 48)
	0 III A				3	35 III	1	15
$a^2G'_4$	32, 887. 91				18, 014. 07	18, 129. 94	12, 819. 05	12, 816. 27
	10 II		4 IV A		40 III	3 IV	4	
c^2F_4	33, 110. 32		16, 265. 59		18, 236. 50	18, 352. 33	13, 041. 50	
	3 II	8 II		4	1	30 III		20
c^2F_3	32, 985. 67	33, 154. 02	(16, 141. 08)	16, 128. 64	18, 111. 87	18, 227. 79		12, 914. 34
	6	2	10 IV	0	40 III	0 IV A		
$c^2D'_3$	33, 538. 96	33, 707. 22	16, 694. 28	16, 681. 91	18, 665. 16	18, 780. 87		
	10	5	0 IV	7 IV		25 III		
$c^2D'_2$	33, 446. 84	33, 614. 85	16, 602. 02	16, 589. 68		18, 688. 85		
	2		15 III A	1 IV A	2 III A			
$d^2D'_3$	36, 870. 95	(37, 039. 77)	20, 026. 84	20, 014. 41	21, 997. 60	(22, 113. 53)		
	2		7 III A	8 IV A		2 III A		
$d^2D'_2$	(36, 765. 83)	36, 933. 33	19, 921. 17	19, 908. 79	(21, 892. 33)	22, 007. 92		
	1		15 III A	7 III A				
d^2P_2	36, 917. 38	(37, 086. 31)	20, 073. 29	20, 060. 88				
	1			10 III A				
d^2P_1		37, 125. 34		20, 100. 36				
							12 IV	
a^2H_6							19, 012. 17	
							2 IV A	8 IV
a^2H_5							18, 916. 33	18, 913. 51
					2		10 IV	0 IV A
$b^2G'_5$					24, 381. 48		19, 186. 62	19, 183. 82
						1 III A	0 IV	10 IV
$b^2G'_4$					(24, 350. 83)	24, 466. 87	19, 155. 84	19, 152. 98
							30 IV	2
d^2F_4	(39, 720. 79)		(22, 876. 15)		(24, 847. 01)		19, 652. 03	19, 649. 16
								10 IV
d^2F_3		(39, 881. 25)		(22, 855. 89)		(24, 955. 01)		19, 641. 33

	a^2D_3	a^2D_2	$a^4F'_5$	$a^4F'_4$	$a^4F'_3$	$a^4F'_2$
			100 II			
$a^4G'_6$			17, 626. 21			
			20 III A	75 II		
$a^4G'_5$			17, 512. 52	17, 579. 59		
	2 II A		2 IV A	30 III A	50 II	
$a^4G'_4$	28, 927. 85		17, 418. 91	17, 485. 93	17, 538. 58	
	0	2		2 IV A	25 III A	45 III A
$a^4G'_3$	28, 854. 54	29, 022. 90		17, 412. 66	17, 465. 19	17, 502. 92
			75 II	20 III		
b^4F_5			19, 673. 53	19, 740. 54		
	0 III A		10 III	60 II	30 III	
b^4F_4	31, 107. 06		19, 598. 09	19, 665. 17	19, 717. 57	
	0 III A	00 III A		25 III	50 II	15 III
b^4F_3	31, 047. 46	31, 216. 03		19, 605. 40	19, 658. 13	19, 695. 82
		0 III A			15 III	40 II
b^4F_2	(31, 004. 30)	31, 172. 71			19, 614. 97	19, 652. 68
	1 III A		40 III	6 III	1	
$b^4D'_4$	32, 583. 28		21, 074. 23	21, 141. 30	21, 193. 87	
	1 III A			30 III	30 III	0 III A
$b^4D'_3$	32, 528. 57	(32, 696. 84)		21, 086. 63	21, 139. 20	21, 176. 86
		0 III A			20 III	30 III
$b^4D'_2$	(32, 480. 89	32, 659. 60			21, 101. 63	21, 139. 20
						15 III
$b^4D'_1$		(32, 637. 40)				21, 117. 45

TABLE 5.—*Combinations in the Sc I spectrum*—Continued

	a^4D_4	a^4D_3	a^4D_2	a^4D_1	$b^4F'_5$	$b^4F'_4$	$b^4F'_3$	$b^4F'_2$
	25 III				12 IV A	2		
a^4F_5	18, 540. 58				17, 879. 85	17, 820. 00		
	6 IV A	20 III			4 IV	10 III A	3	
a^4F_4	18, 685. 36	18, 598. 31			18, 024. 72	17, 964. 93	17, 916. 99	
	1 IV A	8 IV	7 III			2	7 IV	2
a^4F_3	18, 810. 59	18, 723. 47	18, 666. 34			18, 090. 12	18, 042. 12	18, 007. 06
		1 IV A	6 IV A	10 IV			1	4
a^4F_2		18, 807. 44	18, 750. 30	18, 717. 68			18, 126. 06	18, 091. 06
	30 III	8 III			7 IV	2		
$a^4D'_4$	18, 356. 37	18, 269. 16			17, 695. 63	17, 635. 72	(17, 587. 88)	
	8 III	15 III A	6 III			5 IV	1 IV A	
$a^4D'_3$	18, 426. 13	18, 339. 03	18, 281. 85			17, 705. 56	17, 657. 65	(17, 622. 53)
		5 III	2	10 III			2 IV	2
$a^4D'_2$		18, 458. 28	18, 401. 14	18, 368. 51			17, 776. 96	17, 741. 88
			7 III	6 III				3 IV A
$a^4D'_1$			18, 413. 14	18, 380. 54				17, 753. 86
	10 IV	4						
a^4P_3	15, 995. 68	15, 908. 53	(15, 851. 38)					
		8 IV	6	0 IV				
a^4P_2		15, 964. 27	15, 907. 06	15, 874. 20				
			3	4 IV				
a^4P_1			15, 918. 74	15, 886. 16				
		2	5 III				1	
$a^2D'_3$	(18, 544. 36)	18, 457. 33	18, 400. 16			(17, 823. 90)	17, 775. 98	(17, 740. 85)
		4 III A	3 III A				3 IV A	
$a^2D'_2$		18, 383. 28	18, 326. 02	(18, 293. 39)			17, 701. 74	(17, 666. 71)

	$b^4P'_3$	$b^4P'_2$	$b^4P'_1$	a^4G_6	a^4G_5	a^4G_4	a^4G_3
				10 III	1		
a^4F_5				24, 001. 71	23, 931. 15	(23, 876. 05)	
					10 III	1	
a^4F_4					24, 075. 98	24, 020. 90	(23, 979. 44)
						7 III	2
a^4F_3						24, 146. 11	24, 104. 72
							5 III
a^4F_2							24, 188. 70
	5 III A						
$a^4D'_4$	20, 361. 96						
	1 IV A	2 III A					
$a^4D'_3$	20, 431. 67	20, 374. 83					
		1 IV					
$a^4D'_2$	(20, 550. 92)	20, 493. 83	(20, 471. 00)				
			1 IV A				
$a^4D'_1$		(20, 506. 05)	20, 483. 08				
	5	3					
a^4P_3	18, 001. 45	17, 944. 36					
	2	0	3				
a^4P_2	18, 057 18	18, 000. 12	17, 977. 07				
		3	Op?				
a^4P_1		18, 011. 73	17, 988. 81				
$a^2D'_3$	(20, 549. 02)	(20, 493. 04)					
$a^2D'_2$	(20, 475. 88)	(20, 418. 90)	(20, 397. 96)				

TABLE 5.—*Combinations in the Sc I spectrum*—Continued

	$c^4F'_5$	$c^4F'_4$	$c^4F'_3$	$c^4F'_2$	b^4D_4	b^4D_3	b^4D_2	b^4D_1
	2 III A	1			2			
a^4F_5	24,644.31	24,577.24			23,773.35			
		3 III A	1 IV A			2		
a^4F_4	(24,789.11)	24,722.32	24,673.14		(23,918.07)	23,873.21		
			2 III A	0 I V			1	
a^4F_3		(24,847.51)	24,798.42	24,764.69		(23,998.47)	23,965.18	
				1 III A				1
a^4F_2			(24,882.47)	24,848.65			(24,049.20)	24,028.71
	4 III	2			5 III	1 IV A		
$a^4D'_4$	24,460.05	24,393.20	(24,344.88)		23,589.19	23,544.36		
		3 III	2 III A		2 III A	3 III A	2 IV A	
$a^4D'_3$		24,462.98	24,414.06	(24,380.17)	23,658.69	23,613.88	23,580.68	
			3 III A	00		2	2 III A	1 IV A
$a^4D'_2$			24,533.22	24,499.19		23,733.17	23,699.86	23,679.54
				2 III A			2	2 III A
$a^4D'_1$				24,511.56			23,711.95	23,691.60
					6 III	1		
a^4P_3					21,228.52	21,183.50	(21,150.24)	
						3	1	
a^4P_2						21,239.16	21,205.87	(21,185.51)
							1	1
a^4P_1							21,217.71	21,197.33
		2 III A						
$a^2D'_3$		24,581.23	(24,532.26)	(24,498.49)	(23,777.13)	(23,732.21)	(23,698.99)	
				1			1	1
$a^2D'_2$			(24,458.12)	24,424.37		(23,658.07)	23,624.87	23,604.46

	$e^4F'_5$	$e^4F'_4$	$e^4F'_3$	$e^4F'_2$	$f^4F'_5$	$f^4F'_4$	$f^4F'_3$	$f^4F'_2$
	3 III A	0 III A			1	1		
a^4F_5	29,099.03	28,990.00			32,297.18	32,045.41		
	2	2 III A	0 III A		1	1	2d	
a^4F_4	29,243.98	29,134.64	29,027.80		32,441.70	32,189.86	32,064.41	
		2 III A	2 III A	0 III A			1	1
a^4F_3		29,259.82	29,152.99	29,066.45		(32,315.29)	32,189.86	32,142.56
			1	2 III A				1
a^4F_2			29,236.97	29,150.61			(32,273.77)	32,226.38
	2 III A	00						
$a^4D'_4$	28,914.80	28,805.41			(32,112.78)	(31,860.97)		
		1 III A	00					
$a^4D'_3$		28,875.21	28,768.52			(31,930.73)	(31,805.21)	
			0	1				
$a^4D'_2$			28,887.81	28,800.85?			(31,924.43)	(31,877.18)
				1 III A				
$a^4D'_1$				28,813.13				(31,889.24)
a^4P_3								
a^4P_2								
a^4P_1								
$a^2D'_3$		(28,993.65)	(28,886.78)					
$a^2D'_2$			(28,811.64)	(28,726.20)				

TABLE 5.—*Combinations in the Sc I spectrum*—Continued

	$d^4F'_5$	$d^4F'_4$	$d^4F'_3$	$d^4F'_2$	$e^4F'_5$	$e^4F'_4$	$e^4F'_3$	$e^4F'_2$
$a^4G'_6$	6 12, 781. 54 3				(15, 822. 05)			
$a^4G'_5$	12, 895. 13	5 12, 825. 74 2			(15, 935. 64)	(15, 826. 54)		
$a^4G'_4$	(12, 988. 81)	12, 919. 37	4 12, 864. 72 2			(15, 920. 17)	(15, 813. 30)	
$a^4G'_3$		(12, 992. 70)	12, 937. 93	4 12, 899. 07			(15, 886. 63)	(15, 800. 19)
b^4F_5	(10, 734. 20)				6 13, 774. 98	(13, 665. 56) 4h	1	
b^4F_4		(10, 740. 35)			(13, 850. 25)	13, 740. 88	13, 634. 11 3	1
b^4F_3			(10, 745. 10)			(13, 800. 61)	13, 693. 64	13, 607. 36 2
b^4F_2				(10, 749. 32)			(13, 726. 88)	13, 650. 40
$b^4D'_4$					(12, 384. 03)			
$b^4D'_3$						(12, 319. 53)		
$b^4D'_2$							(12, 250. 29)	
$b^4D'_1$								(12, 187. 66)

	$a^4P'_3$	$a^4P'_2$	$a^4P'_1$		$a^2P'_2$	$a^2P'_1$
	15 III A	6 III A	2 IV A		1 IV	
$a^4S'_2$	20, 179. 84	20, 231. 92	20, 260. 86	$x^2D'_3$	21, 740. 34	
	15 III A	10 III A			1 III A	2 IV
b^4P_3	20, 657. 80	20, 709. 83		$x^2D'_2$	21, 686. 15	21, 766. 47
	7 III A	3 IV A	8 III A		3 III	5 III
b^4P_2	20, 601. 47	20, 653. 44	20, 682. 50	$a^2S'_1$	21, 856. 64	21, 937. 02
		7 III A	1 III A		1 III A	
b^4P_1		20, 622. 72	20, 651. 74	$y^2D'_3$	29, 849. 14	
					1	1 IV A
				$y^2D'_2$	29, 751. 08	29, 831. 51

Table 6 gives a list of all the arc lines which have been classified, and is arranged like Table 3. Most of the lines are taken from Meggers's paper, some from King's list, a few from Exner and Haschek, and a number, which were found and measured by one of us (H. N. R.) on the positives sent by Doctor King, are here published for the first time. For convenience of reference the latter are collected in Table 7. The intensities are estimated roughly on King's scale, and the temperature classes, when given, refer only to lines which are conspicuously intensified in the furnace. Though many of these lines are faint, their reality is assured by their agreement with the positions computed from the combination principle, the average discordance, ± 0.019 A, being as good as the precision of the measures admits.

TABLE 6.—*Classified lines of Scandium I*

λ	o–c	Intensity M	Intensity and Class K	ν	Terms
2,692.78	+3	1		37,125.34	$a^2D_2-d^2P_1$
2,706.78	+6	2		36,933.33	$a^2D_2-d^2D'_2$
2,707.95	+4	1		36,917.38	$a^2D_3-d^2P_2$
2,711.36	+4	2		36,870.95	$a^2D_3-d^2D'_3$
2,965.86	0	2		33,707.22	$a^2D_2-c^2D'_3$
2,974.01	+2	5		33,614.85	$a^2D_2-c^2D'_2$
2,980.74	0	6		33,538.96	$a^2D_3-c^2D'_3$
2,988.95	−2	10		33,446.84	$a^2D_3-c^2D'_2$
3,015.35	0	8	8 II	33,154.02	$a^2D_2-c^2F_3$
3,019.33	0	10	10 II	33,110.32	$a^2D_3-c^2F_4$
3,030.74	0	3	3 II	32,985.67	$a^2D_3-c^2F_3$
3,039.76	0		0 III A	32,887.91	$a^2D_3-a^2G'_4$*
3,061.00	−3		0 III A	32,659.60	$a^2D_2-b^4D'_2$*
3,068.17	−1		1 III A	32,583.28	$a^2D_3-b^4D'_4$*
3,073.33	−1		1 III A	32,528.57	$a^2D_3-b^4D'_3$*
3,081.56	+1	1		32,441.70	$a^4F_4-f^4F'_5$?
3,095.35	−1	1		32,297.18	$a^4F_5-f^4F'_5$?
3,102.15	0	1		32,226.38	$a^4F_2-f^4F'_2$?
3,105.67	+2, −1	1		32,189.86	$a^4F_4-f^4F'_4$? $a^4F_3-f^4F'_3$?
3,110.24	−1	1		32,142.56	$a^4F_3-f^4F'_2$?
3,117.82	+1	2 d	Ny?	32,064.41	$a^4F_4-f^4F'_3$?
3,119.67	−2	1		32,045.41	$a^4F_5-f^4F'_4$?
3,202.56	−2		(00) III A	31,216.03	$a^2D_2-b^4F_3$
3,207.01	−1		(0) III A	31,172.71	$a^2D_2-b^4F_2$
3,213.78	−1		(0) III A	31,107.06	$a^2D_3-b^4F_4$
3,219.95	+1		(0) III A	31,047.46	$a^2D_3-b^4F_3$
3,255.69	0	4	6 I A	30,706.63	$a^2D_2-c^2P_2$
3,269.91	0	10	15 II A	30,573.10	$a^2D_2-c^2P_1$
3,273.64	0	15	20 II A	30,538.27	$a^2D_3-c^2P_2$
3,349.22	(0)	?	1 III A	29,849.14	$a^2P'_2-y^2D'_3$?
3,351.20	(0)	?	1 IV A	29,831.51	$a^2P'_1-y^2D'_2$?
3,360.26	+1	?	1 III A	29,751.08	$a^2P'_2-y^2D'_2$?
3,416.68	+1	2	2 III A	29,259.82	$a^4F_3-e^4F'_4$
3,418.53	−2		2	29,243.98	$a^4F_4-e^4F'_5$
3,419.35	0	1		29,236.97	$a^4F_2-e^4F'_3$
3,429.20	0	2	3 III A	29,152.99	$a^4F_3-e^4F'_3$
3,429.48	−1	2	3 III A	29,150.61	$a^4F_2-e^4F'_2$
3,431.36	0	2	3 III A	29,134.64	$a^4F_4-e^4F'_4$
3,435.56	0	3	5 III A	29,099.03	$a^4F_5-e^4F'_5$
3,439.41	+1	?	1 III A	29,066.45	$a^4F_3-e^4F'_2$
3,443.99	−1	?	1 III A	29,027.80	$a^4F_4-e^4F'_3$
3,444.57	0		(2) (II A)	29,022.90	$a^2D_2-a^4G'_3$
3,448.48	−2	?	1 III A	28,990.00	$a^4F_5-e^4F'_4$
3,455.89	0		(2) (II A)	28,927.85	$a^2D_3-a^4G'_4$
3,457.45	0	2	3 III A	28,914.80	$a^4D'_4-e^4F'_5$
3,460.68	0		0	28,887.81	$a^4D'_2-e^4F'_3$
3,462.19	+1	1	2 III A	28,875.21	$a^4D'_3-e^4F'_4$
3,464.67	0		(00) (II A)	28,854.54	$a^2D_3-a^4G'_3$
3,469.65	+2	1	1 III A	28,813.13	$a^4D'_1-e^4F'_2$
3,470.58	+2		(00)	28,805.41	$a^4D'_4-e^4F'_4$
3,471.13	+8??	1		28,800.85	$a^4D'_2-e^4F'_2$??
3,475.03	−1		00	28,768.52	$a^4D'_3-e_4F'_3$
3,498.91	(0)	2	2 III A	28,572.18	$a^4F_5-c^4D_4$?
3,907.49	0	40	75 II	25,584.65	$a^2D_2-b^2F_3$
3,911.81	0	60	100 II	25,556.40	$a^2D_3-b^2F_4$
3,933.37	0	10	20 II	25,416.32	$a^2D_3-b^2F_3$
3,996.61	0	15	30 I	25,014.16	$a^2D_2-b^2D'_3$
4,020.40	+1	50	75 II	24,866.14	$a^2D_2-b^2D'_2$
4,023.23	0	1	2 III A	24,848.65	$a^4F_2-c^4F'_2$
4,023.69	0	70	100 II	24,845.81	$a^2D_3-b^2D'_3$
4,030.67	+2	3		24,802.78	$a^2D'_3-f^2D_3$
4,031.38	+1	2	2 III A	24,798.42	$a^4F_3-c^4F'_3$
4,034.23	0	1	2 III A	24,780.90	$a^4D'_2-f^2D_2$
4,036.87	0	0	2 IV	24,764.69	$a^4F_3-c^4F'_2$

* Photographed by King in furnace.

TABLE 6.—*Classified lines of Scandium I*—Continued

λ	o–c	Intensity M	Intensity and Class K	ν	Terms
4, 043. 79	−1	3	2 III A	24, 722. 32	$a^4F_4-c^4F'_4$
4, 046. 48	0	3	2 III A	24, 705. 88	$a^2D'_2-f^2D_2$
4, 047. 79	−1	10	25 I	24, 697. 89	$a^2D_3-b^2D'_2$
4, 049. 95	−2	2	2 III A	42, 648. 71	$a^4D'_3-f^2D_3$
4, 051. 85	+1	1	1 IV A	24, 673. 14	$a^4F_4-c^4F'_3$
4, 054. 54	0	20	35 I	24, 656. 77	$a^2D_2-b^2P_{1,2}$
4, 056. 59	+1	2	4 III A	24, 644. 31	$a^4F_5-c^4F'_5$
4, 067. 00	+2	2	2 III A	24, 581. 23	$a^2D'_3-c^4F'_4$
4, 067. 66	+4		1	24, 577. 24	$a^4F_5-c^4F'_4$
4, 074. 96	0	3	2 III A	24, 533. 22	$a^4D'_2-c^4F'_3$
4, 078. 56	−1	2	2 III A	24, 511. 56	$a^4D'_1-c^4F'_2$
4, 080. 02	+4		00	24, 499. 19	$a^4D'_2-c^4F'_2$
4, 082. 40	0	30	40 I	24, 488. 51	$a^2D_3-b^2P_{1,2}$
4, 086. 01	−1	1	1 III A	24, 466. 87	$a^2F'_3-b^2G'_4$
4, 086. 66	0	3	4 III	24, 462. 98	$a^4D'_3-c^4F'_4$
4, 087. 15	0	4	8 III	24, 460. 05	$a^4D'_4-c^4F'_5$
4, 093. 12	0	1		24, 424. 37	$a^2D'_2-c^4F'_2$
4, 094. 85	−2	2	1 III A	24, 414. 06	$a^4D'_3-c^4F'_3$
4, 098. 35	0	2		24, 393. 20	$a^4D'_4-c^4F'_4$
4, 100. 32	0	2		24, 381. 48	$a^2F'_4-b^2G'_5$
4, 133. 00	0	5	8 III	24, 188. 70	$a^4F_2-a^4G_3$
4, 140. 29	0	7	10 III	24, 146. 11	$a^4F_3-a^4G_4$
4, 147. 40	0	2		24, 104. 72	$a^4F_3-a^4G_3$
4, 152. 35	0	10	12 III	24, 075. 98	$a^4F_4-a^4G_5$
4, 160. 52	+1	1		24, 028. 71	$a^4F_2-b^4D_1$
4, 161. 87	0		1	24, 020. 90	$a^4F_4-a^4G_4$
4, 165. 20	(0)	10	12 III	24, 001. 71	$a^4F_5-a_4G_5$
4, 171. 55	0	1		23, 965. 18	$a^4F_3-b^4D_2$
4, 177. 48	+1	1	Y?	23, 931. 15	$a^4F_5-a^4G_5$
4, 187. 62	−1	2		23, 873. 21	$a^4F_4-b^4D_3$
4, 202. 19	−3	1−		23, 790. 43	$a^2F_3-e^4F'_2$
4, 204. 54	0	1−		23, 777. 14	$a^2D'_3-b^4D_4$
4, 205. 21	0	2		23, 773. 35	$a^4F_5-b^4D_4$
4, 212. 33	0		2	23, 733. 17	$a^4D'_2-b^4D_3$
4, 212. 46	−4	1		23, 732. 44	$a^2D'_3-b^4D_3$
4, 216. 10	+1	2		23, 711. 95	$a^4D'_1-b^4D_2$
4, 218. 25	+1	2	2 III A	23, 699. 86	$a^4D'_2-b^4D_2$
4, 219. 72	−2	2	2 III A	23, 691. 60	$a^4D'_1-b^4D_1$
4, 221. 87	0	1	1 IV A	23, 679. 54	$a^4D'_2-b^4D_1$
4, 225. 59	+2	2d	2 III A	23, 658. 69	$a^4D'_3-b^4D_4$
4, 231. 64	0	1		23, 624. 87	$a^2D'_2-b^4D_2$
4, 233. 61	0	3	3 III A	23, 613. 88	$a^4D'_3-b^4D_3$
4, 235. 30	0	1		23, 604. 46	$a^2D'_2-b^4D_1$
4, 238. 06	−2	5	6 III	23, 589. 19	$a^4D'_4-b^4D_4$
4, 239. 57	0	2	2 IV A	23, 580. 68	$a^4D'_3-b^4D_2$
4, 246. 11	−4	?	1 IV A	23, 544. 36	$a^4D'_4-b^4D_3$
4, 348. 53	−9	1	tr IV A	22, 989. 83	$a^4F_4-b^2F'_3$
4, 358. 64	−2	2	4 III A	22, 936. 51	$a^2D'_3-b^2F'_4$
4, 375. 18	−9	1	1 III A	22, 849. 80	$a^4D'_2-b^2F'_3$
4, 381. 24	−2	1	tr III A	22, 818. 20	$a^4D'_3-b^2F'_4$
4, 381. 85	−3	1		22, 815. 02	$a^4F_3-b^2G_4$?
4, 389. 60	0	2	2 IV A	22, 774. 74	$a^2D'_2-b^2F'_3$
4, 542. 55	0	2	2 III A	22, 007. 92	$a^2F'_3-d^2D'_2$
4, 544. 68	+1	2	5 III A	21, 997. 60	$a^2F'_4-d^2D'_3$
4, 557. 23	0	3	5 III	21, 937. 02	$a^2P'_1-a^2S'_1$?
4, 573. 99	0	3	6 III	21, 856. 64	$a^2P'_2-a^2S'_1$?
4, 578. 98	−1	1	1 IV A	21, 832. 82	$a^2D'_3-e^2D_3$
4, 592. 94	+1	2	3 IV	21, 766. 47	$a^2P'_1-x^2D'_2$?
4, 598. 46	(0)	1	3 IV	21, 740. 34	$a^2P'_2-x^2D'_3$?
4, 609. 95	−1	1	(0) III A	21, 686. 15	$a^2P'_2-x^2D'_2$
4, 610. 41	0	0		21, 683. 99	$a^2D'_2-e^2D_2$
4, 675. 53	−4	1		21, 381. 99	$a^4F_3-b^2P'_2$
4, 706. 97	0	3		21, 239. 16	$a^4P_2-b^4D_3$
4, 709. 33	−2	6	5 III	21, 228. 52	$a^4P_3-b^4D_4$
4, 711. 73	−1	1		21, 217. 71	$a^4P_1-b^4D_2$

TABLE 6.—*Classified lines of Scandium I*—Continued

λ	o–c	Intensity M	Intensity and Class K	ν	Terms
4, 714. 36	+2	1p?		21, 205. 87	$a^4P_2-b^4D_2$
4, 716. 26		1	(Fowler)	21, 197. 33	$a^4P_1-b^4D_1$
4, 717. 03	−1	1		21, 193. 87	$a^4F'_3-b^4D'_4$
4, 719. 34	−1	1p?		21, 183. 50	$a^4P_3-b^4D_3$
4, 720. 82	0	?	(0) III A	21, 176. 86	$a^4F'_2-b^4D'_3$
4, 728. 76	0	6	5 III	21, 141. 30	$a^4F'_4-b^4D'_4$
4, 729. 23	0, +1	10	30 III	21, 139. 20	$a^4F'_3-b^4D'_3$, $a^4F'_2-b^4D'_2$
4, 732. 30	+2	2	2 IV A	21, 125. 48	$a^2D'_3-b^2P'_2$
4, 734. 10	0	15	15 III	21, 117. 45	$a^4F'_2-b^4D'_1$
4, 737. 65	−1	20	20 III	21, 101. 63	$a^4F'_3-b^4D'_2$
4, 741. 02	−1	30	30 III	21, 086. 63	$a^4F'_4-b^4D'_3$
4, 743. 81	0	40	40 III	21, 074. 23	$a^4F'_5-b^4D'_4$
4, 746. 15	+2	?	(1) IV A	21, 063. 84	$a^4D'_2-b^2P'_1$
4, 748. 97	+2	?	(1) IV A	21, 051. 33	$a^2D'_2-b^2P'_2$
4, 753. 16	0	12	15 I A	21, 032. 77	$a^2D_2-a^2F_3$
4, 758. 91	−4	1	(1) III A	21, 007. 36	$a^4D'_3-b^2P'_2$
4, 763. 12	+2	1	(3) IV A	20, 988. 79	$a^2D'_2-b^2P'_1$
4, 779. 35	0	20	20 I A	20, 917. 52	$a^2D_3-a^2F_4$
4, 791. 50	−1	5	4 I A	20, 864. 48	$a^2D_3-a^2F_3$
4, 827. 28	0	10	4 III A	20, 709. 83	$a^4P'_2-b^4P_2$
4, 833. 66	0	8	2 III A	20, 682. 50	$a^4P'_1-b^4P_2$
4, 839. 44	0	15	10 III A	20, 657. 80	$a^4P'_3-b^4P_3$
4, 840. 46	+1	3	2 IV A	20, 653. 44	$a^4P'_2-b^4P_2$
4, 840. 86	0	1	tr III A	20, 651. 74	$a^4P'_1-b^4P_1$
4, 847. 67	0	7	3 III A	20, 622. 72	$a^4P'_2-b^4P_1$
4, 852. 08	+7?	1		20, 603. 98	$a^4F_2-d^2D_2$?
4, 852. 67	0	7	2 III A	20, 601. 47	$a^4P'_3-b^4P_2$
4, 859. 17	+2	?	(0) IV A	20, 573. 92	$a^4F_3-d^2D_3$
4, 878. 16	+4	1	(2) IV	20, 493. 83	$a^4D'_2-b^4P'_2$
4, 880. 72	+1	?	(1) IV A	20, 483. 08	$a^4D'_1-b^4P'_1$
4, 893. 00	−1	1	(1) IV A	20, 431. 67	$a^4D'_3-b^4P'_3$
4, 906. 65	−3	2	(2) III A	20, 374. 83	$a^4D'_3-b^4P'_2$
4, 909. 75	0	5	3 III A	20, 361. 96	$a^4D'_4-b^4P'_3$
4, 922. 84	−1	4	(2) III A	20, 307. 82	$a^2D'_3-a^2D_3$
4, 934. 25	0	2	(1) IV A	20, 260. 86	$a^4P'_1-a^4S'_2$
4, 935. 75	+6	2	(1) III A	20, 254. 71	$a^4D'_2-d^2D_2$
4, 941. 31	−1	6	2 III A	20, 231. 92	$a^4P'_2-a^4S'_2$
4, 951. 68	−2	1	(1) IV A	20, 189. 55	$a^4D'_3-d^2D_3$
4, 954. 06	0, +2	15	5 III A	20, 179. 84	$a^4P'_3-a^4S'_2$, $a^2D'_2-d^2D_2$
4, 973. 65	(0)	10	3 III A	20, 100. 36	$b^2D_2-d^2P_1$
4, 980. 36	−2	15	4 III A	20, 073. 29	$b^2D_3-d^2P_2$
4, 983. 44	+1	7	2 III A d?	20, 060. 88	$b^2D_2-d^2P_2$
4, 991. 91	−1	15	5 III A	20, 026. 84	$b^2D_3-d^2D'_3$
4, 995. 01	0	1	(1) IV A	20, 014. 41	$b^2D_2-d^2D'_2$
5, 018. 39	+2	7	(2) III A	19, 921. 17	$b^2D_3-d^2D'_2$
5, 021. 51	0	8	(2) IV A	19, 908. 79	$b^2D_2-d^2D'_2$
5, 064. 31	+1	20	10 III	19, 740. 54	$a^4F'_4-b^4F_5$
5, 068. 85	0	5	2 III	19, 722. 86	$a^2D'_3-c^2D_3$
5, 070. 21	+1	30	40 III	19, 717. 57	$a^4F'_3-b^4F_4$d?
5, 075. 81	−3	15	10 III	19, 695. 82	$a^4F'_2-b^4F_3$
5, 081. 56	−1	75	125 II	19, 673. 53	$a^4F'_5-b^4F_5$
5, 083. 72	−2	60	80 II	19, 665. 17	$a^4F'_4-b^4F_4$
5, 085. 54	0	50	40 II	19, 658. 13	$a^4F'_3-b^4F_3$
5, 086. 95	0	40	40 II	19, 652. 68	$a^4F'_2-b^4F_2$
5, 087. 12	−1	30	10 IV ?	19, 652. 03	$a^2G_5-d^2F_4$
5, 087. 86	+1		2	19, 649. 16	$a^2G_4-d^2F_4$, $a^4D'_4-c^2D_2$
5, 089. 89	(0)	10	8 IV	19, 641. 33	$a^2G_4-d^2F_3$
5, 096. 73	0	15	30 III	19, 614. 97	$a^4F'_3-b^4F_2$
5, 099. 22	+3	25	40 III	19, 605. 40	$a^4F'_4-b^4F_3$
5, 101. 12	−2	10	20 III	19, 598. 09	$a^4F'_5-b^4F_4$
5, 107. 37	+1	1		19, 574. 11	$a^2D'_2-c^2D_2$
5, 210. 52	0	10	20 IV	19, 186. 62	$a^2G_5-b^2G'_5$

TABLE 6.—*Classified lines of Scandium I*—Continued

λ	o–c	Intensity M	Intensity and Class K	ν	Terms
5,211.28	0	0	(0) IV A	19,183.82	$a^2G_4-b^2G'_5$
5,218.89	0	?	(0) IV	19,155.84	$a^2G_5-b^2G'_4$
5,219.67	+1	?	10 IV	19,152.98	$a^2G_4-b^2G'_4$
5,258.33	0	12	15 IV	19,012.17	$a^2G_5-a^2H_6$
5,284.97	0	2	tr IV A	18,916.33	$a^2G_5-a^2H_5$
5,285.76	0	8	10 IV	18,913.51	$a^2G_4-a^2H_5$
5,301.94	−1	4	2 II A	18,855.79	$a^2D_2-a^2P_2$
5,314.68	0	1	tr IV A	18,810.59	$a^4F_3-a^4D_4$
5,315.57	+2	1	tr IV A	18,807.44	$a^4F_2-a^4D_3$
5,323.09	+4	0	tr IV A	18,780.87	$a^2F'_3-c^2D'_3$
5,331.77	0	6	3 IV A	18,750.30	$a^4F_2-a^4D_2$
5,339.41	+2	8	8 IV	18,723.47	$a^4F_3-a^4D_3$
5,341.06	+2	10	8 IV	18,717.68	$a^4F_2-a^4D_1$
5,342.96	0	9	10 II A	18,711.03	$a^2D_2-a^2P_1$
5,349.30	−1	25	50 III	18,688.85	$a^2F'_3-c^2D'_2$
5,349.71	+1	7	15 II A	18,687.42	$a^2D_3-a^2P_2$
5,350.30	−1	6	4 IV A	18,685.36	$a^4F_4-a^4D_4$
5,355.75	0	7	8 III	18,666.34	$a^4F_3-a^4D_2$
5,356.09	−1	40	60 III	18,665.16	$a^2F'_4-c^2D'_3$
5,375.34	−1	20	20 III	18,598.31	$a^4F_4-a^4D_3$
5,383.08	−3		(2) I A	18,571.57	$a^2D_2-a^4P_3$
5,392.08	0	25	30 III	18,540.58	$a^4F_5-a^4D_4$
5,399.34	+4		(3) I A	18,515.64	$a^2D_2-a^4P_2$
5,402.72	+1		(5) I A	18,504.06	$a^2D_2-a^4P_1$
5,416.12	0	5	2 III	18,458.28	$a^4D'_2-a^4D_3$
5,416.40	0	2		18,457.33	$a^2D'_3-a^4D_3$
5,422.30	−1	1		18,437.25	$a^2P_1-b^2P'_2$
5,425.57	−2	8	2 III	18,426.13	$a^4D'_3-a^4D_4$
5,429.40	0	7	2 III	18,413.14	$a^4D'_1-a^4D_2$
5,432.36	+2		(1) I A	18,403.10	$a^2D_3-a^4P_3$
5,432.94	−2	2?		18,401.14	$a^4D'_2-a^4D_2$
5,433.23	−1	5	2 III	18,400.16	$a^2D'_3-a^4D_2$
5,438.22	−3	4	1 III A	18,383.28	$a^2D'_2-a^4D_3$
5,439.03	+2	6	2 III	18,380.54	$a^4D'_1-a^4D_1$
5,442.59	0	10	2 III	18,368.51	$a^4D'_2-a^4D_1$
5,446.19	−2	30	20 III	18,356.37	$a^4D'_4-a^4D_4$
5,447.39	+3	3	1 IV	18,352.33	$a^2F'_3-c^2F_4$
5,448.84	+1	0	(I A)	18,347.45	$a^2D_3-a^4P_2$
5,451.34	−1	15	6 III A	18,339.03	$a^4D'_3-a^4D_3$
5,455.21	−1	3	1 III A	18,326.02	$a^2D'_2-a^4D_2$
5,465.20	−1	3	tr IV A	18,292.52	$a^2P_2-b^2P'_2$
5,468.39	−1	6	2 III	18,281.85	$a^4D'_3-a^4D_2$
5,472.19	+3	8	3 III	18,269.16	$a^4D'_4-a^4D_3$
5,481.99	+1	40	100 III	18,236.50	$a^2F'_4-c^2F_4$
5,484.61	1	30	80 III	18,227.79	$a^2F'_3-c^2F_3$
5,514.21	0	35	80 III	18,129.94	$a^2F'_3-a^2G'_4$
5,515.39	+2	1		18,126.06	$a^4F_2-b^4F'_3$
5,519.71	+1		1	18,111.87	$a^2F'_4-c^2F_3$
5,520.50	0	50	100 III	18,109.28	$a^2F'_4-a^2G'_5$
5,526.06	−1	4		18,091.06	$a^4F_2-b^4F'_2$
5,526.35	0		2	18,090.12	$a^4F_3-b^4F'_4$
5,536.43	−4	2		18,057.18	$a^4P_2-b^4P'_3$
5,541.05	+2	7	3 IV	18,042.12	$a^4F_3-b^4F'_3$
5,546.40	−2	4	1 IV	18,024.72	$a^4F_4-b^4F'_5$
5,549.68	0	3		18,014.07	$a^2F'_4-a^2G'_4$
5,550.40	−1	3		18,011.73	$a^4P_1-b^4P'_2$
5,551.84	+4	2		18,007.06	$a^4F_3-b^4F'_2$
5,553.57	−2	5		18,001.45	$a^4P_3-b^4P'_3$
5,553.98	−3	0		18,000.12	$a^4P_2-b^4P'_2$
5,557.47	−1		Op	17,988.81	$a^4P_1-b^4P'_1$
5,561.10	0	3		17,977.07	$a^4P_2-b^4P'_1$
5,564.86	−2	10	4 III A	17,964.93	$a^4F_4-b^4F'_4$
5,571.24	0	3		17,944.36	$a^4P_3-b^4P'_2$
5,579.75	−2	3		17,916.99	$a^4F_4-b^4F'_3$
5,591.34	+1	12	15 IV A	17,879.85	$a^4F_5-b^4F'_5$

TABLE 6.—*Classified lines of Scandium I*—Continued

λ	o–c	Intensity M	Intensity and Class K	ν	Terms
5,593.39	+1	5		17,873.30	$a^2F_4-b^2F'_4$
5,604.19	−1	3	1 IV	17,838.85	$a^2F_3-b^2F'_3$
5,608.90	+1	1−		17,823.87	$a^2D'_3-b^4F'_4$
5,610.12	+3	2		17,820.00	$a^4F_5-b^4F'_4$
5,623.70	−2	2	1 IV	17,776.96	$a^4D'_2-b^4F'_3$
5,624.01	+1	1		17,775.98	$a^4D'_3-b^4F'_3$
5,631.02	0	3	1 IV A?	17,753.86	$a^4D'_1-b^4F'_2$
5,634.82	−4	2		17,741.88	$a^4D'_2-b^4F'_2$
5,646.37	+1	5	4 IV	17,705.59	$a^4D'_3-b^4F'_4$
5,647.60	+3	3	1 IV A	17,701.74	$a^2D'_2-b^4F'_3$
5,649.55	−1	7	6 IV	17,695.63	$a^4D'_4-b^4F'_5$
5,661.70	0	1	tr IV A	17,657.65	$a^4D'_3-b^4F'_3$
5,668.74	+3		2	17,635.72	$a^4D'_4-b^4F'_4$
5,671.80	0	100	200 II	17,626.21	$a^4F'_5-a^4G'_6$
5,686.84	0	75	150 II	17,579.59	$a^4F'_4-a^4G'_5$
5,691.33	0	?	(0) IV	17,565.72	$a^2P_1-d^2D_2$
5,700.14	−1	50	100 II	17,538.58	$a^4F'_3-a^4G'_4$
5,708.62	0	20	15 III A	17,512.52	$a^4F'_5-a^4G'_5$
5,711.75	0	45	100 III A	17,502.92	$a^4F'_2-a^4G'_3$
5,717.30	+1	30	15 III A	17,485.93	$a^4F'_4-a^4G'_4$
5,720.95	−2	1	tr IV	17,474.78	$a^2P_2-d^2D_3$
5,724.09	+1	25	15 III A	17,465.19	$a^4F'_3-a^4G'_3$
5,739.30	−2	2	2 IV A	17,418.91	$a^4F'_5-a^4G'_4$
5,741.36	−3	2	1 IV A	17,412.66	$a^4F'_4-a^4G'_3$
5,894.63	+3	3	(2) IV	16,959.90	$a^2P_1-c^2D_2$
5,919.11	+4	5	tr IV A	16,889.76	$a^2P_2-c^2D_3$
5,961.49	−1	6	4 IV	16,769.69	$a^2F_4-e^2D_3$
5,969.19	0	5	3 IV	16,748.06	$a^2F_3-e^2D_2$
5,988.42	0	10	20 IV	16,694.28	$b^2D_3-c^2D'_3$
5,992.86	−2	0		16,681.91	$b^2D_2-c^2D'_3$
6,021.70	+2	?	(0) IV	16,602.02	$b^2D_3-c^2D'_2$
6,026.18	+1	7	15 IV	16,589.68	$b^2D_2-c^2D'_2$
6,146.25	+3	4	(3) IV A	16,265.59	$b^2D_3-c^2F_4$
6,193.66	−2	2	(3) II A	16,141.09	$a^2D_2-a^4D'_3$
6,198.44	0	4	(2) IV A	16,128.64	$b^2D_2-c^2F_3$
6,210.68	0	30	200 I A	16,096.85	$a^2D_2-a^2D'_2$
6,231.76	+2		(2) (I A)	16,042.40	$a^2D_3-a^4D'_4$
6,239.40	−2	8	20 II A	16,022.76	$a^2D_2-a^2D'_3$
6,239.78	0	15	100 I A	16,021.78	$a^2D_2-a^4D'_2$
6,244.51	+2		(1) (I.A)	16,009.65	$a^2D_2-a^4D'_1$
6,249.96	+1	10	15 IV	15,995.68	$a^4P_3-a^4D_4$
6,258.97	+2	20	100 I A	15,972.65	$a^2D_3-a^4D'_3$
6,262.26	+2	8	10 IV	15,964.27	$a^4P_2-a^4D_3$
6,273.16	0	?	(0) IV	15,936.53	$b^2D'_2-f^2D_2$
6,276.30	−1	9	15 II A	15,928.56	$a^2D_3-a^2D'_2$
6,280.17	+2	3		15,918.74	$a^4P_1-a^4D_2$
6,284.20	+5	4		15,908.53	$a^4P_3-a^4D_3$
6,284.78	0	6		15,907.06	$a^4P_2-a^4D_2$
6,293.05	+2	4	(2) IV	15,886.16	$a^4P_1-a^4D_1$
6,297.79	+10	?	(0) IV	15,874.20	$a^4P_2-a^4D_1$?
6,305.68	+2	40	400 I A	15,854.34	$a^2D_3-a^2D'_3$
6,306.00	0	10	20 I A	15,853.54	$a^2D_3-a^4D'_2$
6,322.74	−2	2		15,811.56	$b^2D'_3-f^2D_3$
6,344.84	+1	3	5 II A	15,756.49	$a^2D_2-a^4F_3$
6,362.28	+5		(2) (I.A)	15,713.30	$a^2D_3-a^4F_4$
6,378.83	+1	8	40 I A	15,672.53	$a^2D_2-a^4F_2$
6,413.37	+2	10	50 I A	15,588.12	$a^2D_3-a^4F_3$
6,448.10	+1	2	1 II A	15,504.17	$a^2D_3-a^4F_2$
6,557.84	0	3	15 IV	15,244.65	$a^2F_4-d^2D_3$
6,558.05	−11	2		15,244.23	$a^2F_3-d^2D_2$
6,714.60	−3	2		14,888.82	$b^2D'_2-b^4D_3$
6,819.51	−2	20		14,659.77	$a^2F_4-c^2D_3$
6,829.52	−3	15		14,638.29	$a^2F_3-c^2D_2$
7,138.13	0	6		14,005.42	$b^2D'_2-b^2F'_3$
7,169.13	+8	8		13,944.85	$b^2D'_3-b^2F'_4$

TABLE 6.—*Classified lines of Scandium I*—Continued

λ	o–c	Intensity M	Intensity and Class K	ν	Terms
7,257.56	−12?	6		13,774.98	$b^4F_5-e^4F'_5$
7,275.55	+4	4h		13,740.88	$b^4F_4-e^4F'_4$
7,300.65	+5,0	3		13,693.64	$b^4F_3-e^4F'_3$ / $b^2D_3-c^2P_2$?
7,323.78	−2	2		13,650.40	$b^4F^2-e^4F'_2$
7,332.53	+4	1−		13,634.11	$b^4F_4-e^4F'_3$
7,346.94	−3	1−		13,607.36	$b^4F_3-e^4F'_2$
7,524.11	0	7		13,286.96	$b^2F_3-b^2F'_3$
7,553.96	−1	6		13,234.45	$b^2F_4-b^2F'_4$
7,574.44	+2	7		13,198.67	$b^2P_{1,2}-e^2D_3$
7,617.45	−7	5		13,124.15	$b^2P_{1,2}-e^2D_2$
7,665.72	+2	4		13,041.50	$a^2G_5-c^2F_4$
7,697.76	0	10		12,987.23	$b^2F_3-b^2G_4$
7,727.09	+4	2		12,937.93	$a^4G'_3-d^4F'_3$
7,729.73	0	7		12,933.51	$b^2F_4-b^2G_5$
7,738.18	0	2		12,919.37	$a^4G'_4-d^4F'_4$
7,741.20	−2,−15,+20	20		12,914.34	$a^2G_5-a^2G'_5$ / $a^2G_4-c^2F_3$ / $b^2D'_2-e^2D_2$
7,742.82	+4	1		12,911.54	$a^2G_4-a^2G'_5$
7,750.37	(0)	4		12,899.07	$a^4G'_3-d^4F'_2$
7,752.72	+2	3		12,895.13	$a^4G'_5-d^4F'_5$
7,771.06	−4	4		12,864.72	$a^4G'_4-d^4F'_3$
7,785.17	−3	6		12,841.40	$b^2D'_3-e^2D_3$
7,794.68	0	5		12,825.74	$a^4G'_5-d^4F'_4$
7,798.75	+2	1		12,819.05	$a^2G_5-a^2G'_4$
7,800.44	0	15		12,816.27	$a^2G_4-a^2G'_4$
7,821.64	+3	6		12,781.54	$a^4G'_6-d^4F'_5$
7,830.78	+5	1		12,766.61	$b^2D'_3-e^2D_2$
8,003.27	−1	2		12,491.46	$b^2P_{1,2}-b^2P'_2$
8,043.44	−8	1		12,429.04	$b^2P_{1,2}-b^2P'_1$
8,181.32	+4	1		12,219.60	$b^2D'_2-b^2P'_1$
8,196.98	−5	3		12,196.26	$b^2F_3-e^2D_2$
8,239.05	+7	1		12,133.99	$b^2D'_3-b^2P'_2$
8,241.13	−10	4		12,130.93	$b^2F_4-e^2D_3$

TABLE 7.—*New arc lines (Sc I)*

	Intensity	Class	o–c		Intensity	Class	o–c
3,039.76	0	III A	0	3,475.03	(00)		−1
3,061.00	0	III A	−3				
3,068.17	1	III A	−1	4,067.66	1		+4
3,073.33	1	III A	−1	4,080.02	00		+4
3,202.56	00	III A	−2	5,383.08	(2)	I A	−3
				5,399.34	(3)	I A	+4
3,207.01	0	III A	−1	5,402.72	(5)	I A	+1
3,213.78	0	III A	−1				
3,219.95	0	III A	+1	5,432.36	(1)	I A	+2
3,418.53	2	(*)	−2	5,519.71	1		+1
3,444.57	(2)	II A	0	5,557.47	0p		−1
				5,668.74	2		+3
3,455.89	(2)	II A	0	6,231.76	(2)	I A	+3
3,460.68	(0)		0				
3,464.67	(00)	II A	0	6,244.51	(1)	I A	+2
3,470.58	(00)		+2	6,362.28	(2)	I A	+6

* May be partly due to Fe 3,418.51.

The average discordance, without regard to sign, between the observed and computed wave lengths is ±0.015 A—twice as great as for the spark lines. This difference arises mainly from large residuals for lines in the red and infra-red. For 54 lines with wave

lengths greater than λ6,270 the average residual is ±0.033, while for the remaining 295 lines, it is ±0.0114, corresponding to a probable error of ±0.0097 A, which, though larger than for the spark lines, may be regarded as satisfactory. The few residuals which exceed 0.03 A all belong to weak lines.

IV. THEORETICAL INTERPRETATION OF THE OBSERVED TERMS

Recent theoretical advances have made it possible to go behind the complex of observed spectral terms to the configurations of the atom which produce them.[15] A brief summary of this theory may be given, largely to explain the notation here employed, which differs from that of Hund's original paper, though it is in close agreement with that of his forthcoming book.

In accordance with Bohr's principles, each electron in an atom is supposed to be in a definite state, which will here be called an "orbit" for convenience, with due recognition of the possibility or probability of other interpretations. Such an orbit may be characterized by its total and azimuthal quantum numbers, 1_1, 3_2, 3_3, etc., in Bohr's notation, or equally well, by a notation like that used by spectroscopists, 1*s*, 3*p*, 3*d*, etc., the letters, *s*, *p*, *d*, *f*, taking the place of the subscripts 1, 2, 3, 4. The latter notation has the advantage of escaping the present uncertainty regarding the absolute values of the azimuthal quantum numbers.

Only a certain number of orbits of a given type; for example, 2*p*, can occur in an atom, and a complete group of the sort forms a "closed shell" which is not concerned in the production of optical spectra, which depend solely on the "valency electrons" outside the completed groups.

When there is but one of these electrons, as in the alkali metals, the spectroscopic terms correspond exactly to the orbits of this electron, and all belong to a doublet system; thus in sodium the 3*s* orbit (corresponding to the normal state of the atom) gives the term 3^2S_1, the 4*p* orbit the terms 4^2P_2, 4^2P_1, etc., the duplicity of the terms being attributable to the "spinning electron." It should be noted that the small letters *s*, *p*, *d* are used to denote electron orbits, and the capital letters S, P, D to denote spectroscopic terms.[16]

When, however, two or more valency electrons are present the spectroscopic terms are determined by a combination of the influence of the two electrons, which may be formally represented by a composition of the vectors representing the orbital angular momenta into a resultant vector, and of their rotational momenta into a

[15] See especially F. Hund, Zs. f. Phys., 33, pp. 345-371; 1925.
[16] J. C. Slater, Phys. Rev., 28, p. 293; 1926.

second vector. These two vectors define a multiple spectroscopic term. In this case there is no longer a simple correspondence between the letters representing the orbits and those representing the terms, but the latter may be found from the former by definite rules.

If to any group of electrons one additional electron is added, each arrangement of the original group (corresponding, for example, to a term in the spark spectrum) will give rise to one or more arrangements of the new group (in our example terms in the arc spectrum). The new terms are, in general, of multiplicity greater and less by unity than the old; thus a triplet term gives rise to both doublet and quartet terms (though a singlet term gives rise only to doublets).

As regards the name (letter) of the term, the addition of an *s* electron leaves this unaltered, while that of others may most briefly be stated by the following:

Original term_____	S	P	D	F	G
Results of adding a *p* electron____	P	S P D	P D F	D F G	F G H
Results of adding a *d* electron____	D	P D F	S P D F G	P D F G H	D F G H I

When, however, the electron which is added has the same total quantum number as one or more of those already present in the atom, Pauli's restriction principle comes into play, and only a part of the terms which might otherwise be expected are actually present, The results of the detailed discussion, so far as they are needed here. are as follows: d^2, d^3, etc., denoting groups of two, three, etc., *d* electrons with the same total quantum number.

The configuration

s^2 gives ^1S
p^2 gives $^3P'$; ^1S, ^1D
d^2 gives $^3P'$, $^3F'$; ^1S, ^1D, ^1G
d^3 gives $^4P'$, $^4F'$; $^2P'$, $^2D'$, $^2F'$, $^2G'$, $^2H'$, ^2D

Both in this case and in the simpler one previously discussed the relative levels of the more important terms are approximately predictable by Hund's rule, for which he has given good theoretical reasons. The terms of greater multiplicity are, in general, lower than those of smaller multiplicity and those of large apparent azimuthal quantum number lower than those of small. Thus, of the terms arising from the d^2 configuration, the triplets lie lower than the singlets and $^3F'$ lower than $^3P'$.

The number of terms corresponding to the possible configurations in a complex atom is very large. Which of them can combine to give spectral lines is determined by a rule due to Heisenberg, according to which one electron must change its azimuth quantum number by a unit (changing from *s* to *p*, *p* to *d*, etc.) while either the other electrons do not change or one shifts by two units (*s* to *d*, *p* to *f*, etc.).

It follows at once that a transition accompanied by the production of a spectral line can occur only between a configuration in which the total number of p and f electrons, taken together, is odd, and one in which it is even (or zero). This proposition accounts fully for the transition rules found empirically by Laporte[17] and by Russell.[18] There are two sets of terms in all complex spectra, such that the members of each do not combine *inter se*, while they combine freely with those of the other set. It may be suggested that these two sets be called "even" and "odd," according to the number of p and f electrons in the atomic configuration.

The well-accepted usage of denoting the "anomalous" terms (that is, those of sorts which do not appear in the spectra of the alkali metals) by accents may be harmonized with this by the following notation.[19]

Even terms	S, P′, D, F′, G, H′, etc.
Odd terms	S′, P, D′, F, G′, H, etc.

This scheme agrees with the generally adopted notation for all the simpler spectra (of the types of sodium, calcium, and aluminium), and provides a simple and definite rule for the more complex cases. The normal state of most atoms corresponds to an even configuration, the exceptions being the elements homologous with aluminium, phosphorus, and chlorine, and some of the rare earths.

Combinations between odd and even terms, though all are "permissible," give rise to lines of very different strength. The strongest lines (as might be expected, and as the correspondence principle indicates) arise from those transitions in which only a single electron orbit changes, while the remainder of the configuration remains unaltered; that is, between terms which can be obtained by adding an electron to the same state of the atom in its next higher degree of ionization, and are, therefore, "built up" from the same term in the spectrum of the more highly ionized state. Transitions involving rearrangements in the rest of the atom are evidently much less probable. The resulting lines are often absent, or, when present, are fainter than intersystem combinations between terms of different multiplicities which are related as described above.

Finally, a word may be said regarding series in complex spectra. Theoretically they should be very numerous, for any one of the valency electrons can change to orbits of successively higher radial quantum number. Practically it is found that even the second member usually gives rise to rather faint lines, while the third member

[17] Zs. f. Phys., **23**, p. 135 or 261; 1924.

[18] Science, **69**, p. 512; June 6, 1924.

[19] Equivalent to the rule given by Heisenberg or by Sommerfeld. Three lectures on Atomic Physics (London, 1926), 643.

has been detected in only a few instances. These series, instead of all having the same limit, as is the case in sodium, will have many different limits, corresponding to the various terms of the next higher spectrum, upon which the individual terms are built up. In certain cases, series converging to several different limits, corresponding to low metastable terms in the succeeding spectrum, have actually been observed.[20] For a satisfactory study of the series in any complex spectrum, therefore, it is necessary that the succeeding spectrum shall have been analyzed sufficiently to determine the relative levels of the important low terms.

When the limiting term is multiple, the various components of the terms derived from it converge to different components of the limiting term. This matter has been discussed by Hund,[21] and it may suffice to say here that the component of highest inner quantum number in each derived term always has as its limit the component of highest inner quantum number in the limiting term.

One more point deserves mention. In complex spectra a term may, in general, be regarded with equal justification as belonging to two or more series. For example, the configuration $3d.4p$ may be followed by $3d.5p$; $3d.mp$, giving a series with the $3d$ configuration of the next stage of ionization as its limit, or by $4d.4p$; $md.4p$, giving another series with the $4p$ configuration as limit. In such a case as iron, every term would belong to half a dozen series were it not for the limitations imposed by the presence of equivalent electrons, and Pauli's restriction principle. It follows that it is impossible to assign a definite total quantum number to an individual term in a complex spectrum. Even in the simple example just given, the total quantum number is 3 in one series and 4 in the other. Moreover, if term values are counted from the limit of any given series, say the lowest limit, they will give an erroneous idea of the distance from the limit in the case of most of the other series. This strongly supports the policy, now widely adopted, of measuring term values upward from the lowest known level, and also that here suggested, of lettering the separate terms, $a\ ^3F$, $b\ ^3F$, etc., instead of attempting to assign total quantum numbers to them.

V. INTERPRETATION OF THE TERMS OF Sc II

We may now apply these principles to the scandium spectrum, taking up the simpler cases first. Scandium belongs to the first long period, in which electron orbits of types $4s$, $3d$, and $4p$ are built onto the completed argon shell.

In Sc III there is but a single valency electron, which, in its normal state is in a $3d$ orbit. The next lowest state corresponds to the $4s$

[20] O. Laporte, Proc. Nat. Acad. Sci., **12**, p. 496, 1926.
[21] Zs. f. Phys., **34**, p. 296; 1925.

orbit, and $4p$ follows. The ultimate lines of Sc III are, therefore, $3\ ^2D-4\ ^2P$, and the next most prominent $4\ ^2S-4\ ^2P$. These have been conclusively identified by Gibbs and White, and additional lines have been found by Stanley Smith. The resulting term values, measuring upward from the lowest level $3\ ^2D_2$, are as follows:

$3\ ^2D_2 = 0$	$4\ ^2P_1 = 62,102$
$3\ ^2D_3 = 198$	$4\ ^2P_2 = 62,576$
$4\ ^2S_1 = 25,537$	$4\ ^2D_2 = 122,254$
	$4\ ^2D_3 = 122,299$

The transition $4\ ^2S-4\ ^2P$ gives the strong lines at 2699 and 2734 A, which appear in the arc. The ionization potential is 24.65 volts.

In the singly ionized atom, we should anticipate the following configurations of the two valency electrons and the corresponding terms. The observed terms with which they have been identified are given in the column at the right.

TABLE 8.—*Predicted and observed terms in Sc II*

Configuration	Predicted terms	Observed terms
$(3d)^2$	$^3P', ^3F'$ $^1S, ^1D, ^1G$	a^3P', a^3F' a^1S, b^1D, a^1G
$3d.4s$	^3D ^1D	a^3D a^1D
$(4s)^2$	^1S	
$3d.4p$	$^3P, ^3D', ^3F$ $^1P, ^1D', ^1F$	a^3P, a^3D', a^3F a^1P, a^1D', a^1F
$4s.4p$	^3P ^1P	b^3P
$3d.4d$	$^3S, ^3P', ^3D, ^3F', ^3G$ $^1S, ^1P', ^1D, ^1F', ^1G$	$a^3S, b^3P', c^3D, b^3F', a^3G$ $a^1S, a^1P', d^1D, a^1F', b^1G$
$3d.5s$	^3D ^1D	b^3D c^1D
$(4p)^2$	$^3P'$ $^1S, ^1D$	c^3P'

In this case the identification of all the observed terms is simple and unambiguous. The $3d$ and $4s$ electrons are evidently a good deal more firmly bound than the $4p$; the lowest terms should, therefore, be "even" and of the types listed above. The agreement with the observed low terms is excellent. Hund's rules are satisfied, the ^3D term lying below the ^1D term of the same origin, and $^3F'$ lower than $^3P'$. Among the singlets, however, $b\ ^1D$, and $a\ ^1S$ are both lower than $a\ ^1G$. Such deviations from Hund's rule are common among terms of a similar sort in other spectra.

The ^1S term arising from the configuration $(4s)^2$ has not been found. The probable reason will be discussed later.

These low even terms should combine with a set of odd terms, which are again found, in excellent agreement with prediction (as

has been pointed out long ago by Hund, in the case of the triplet system). The two "triads" P, D′, F, in the singlet and triplet systems, are conspicuous. Strong lines result from the combinations of these triads with low terms arising from both configurations, $(3d)^2$ and $3d.4s$, and this is to be expected, for in one transition an electron changes from a $3d$ to a $4p$ orbit, the second electron remaining all the time in a $3d$ state. The isolated higher ^{3}P term gives a strong combination with ^{3}D, and none at all with ^{3}P′; and this again was to be expected, for in the first case one electron jumps from $3d$ to $4p$, leaving the other in the $4s$ orbit, while in the second transition one would have to change from $3d$ to $4s$ and the other simultaneously from $3d$ to $4p$. Such transitions, when interpreted by means of the correspondence principle, correspond to terms in the expansion which can arise only from the mutual perturbations of the electrons considered as oscillators; and it is well known that, in the lighter atoms, when the multiplet separations are small, all such "perturbation" effects are weak.

The ^{1}P term arising from this configuration may be expected to lie higher than $b\,^3$P, and its combination with $a\,^1$D may give rise to the unclassified line at λ2,273, or to some other line beyond the limit of present observations.

Passing now to the high even terms, corresponding to configurations in which one of the electrons is in an orbit of higher radial quantum number than the permissible minimum, we find among the triplets the whole of the predicted "pentad" S, P′, D, F′, G, combining strongly with the P, D′, F triad, to give the "supermultiplet" already discussed (cf. p. 331), and giving no perceptible combinations with b^3P, again in accordance with theory. The corresponding pentad of singlet terms has apparently been fully identified. The ^{1}S and ^{1}G terms each give but a single line; but the relative intensities of the lines and levels of the terms make the identification practically certain. The isolated terms b^3D and c^1D, which lie lower than those of the pentads, may be ascribed to the configuration $3d.5s$. Finally, the highest term of all, c^3P′, combines with b^3P (as should be the case if it arose from the configuration $(4p)^2$. Its combinations with the other odd terms lie in the unobserved region beyond λ2,500.

Further evidence in favor of this assignment is found in the magnitude of the triplet separations. According to the approximate theory recently developed by Slater [22] the separations of the extreme components of all terms which arise from configurations in which all the electrons involved are of the same sort, or else are s electrons, should be the same after division by the factors 1, 2, 3, . . . for P, D, F terms; and there is also good reason to believe that the resulting

[22] Phy. Rev., 28, p. 312; 1926.

numbers will not differ much from those derived from corresponding terms of the atom in the next higher degree of ionization.

Two terms, b^3P and c^3P', arise from configurations involving only $4p$ and s electrons. Their extreme separations are 343 and 346, agreeing closely with this rule, while that of the parent 4 ^2P term in Sc III is 475. For the terms which involve only $3d$ electrons and s electrons, the separations are 178 for a^3D, 185 for a^3F', 91 for a^3P', and 192 for b^3D, while that for 3 ^2D in Sc III is 205. Dividing by the appropriate factors we have 89, 63, 91, and 96 against 102 for Sc III. Though the rule is clearly only roughly true the difference between the two sets of terms is conspicuous.

The separations in the pentad of origin $3d.4d$ are interesting. If the intervals between the individual components are divided by the larger of the two inner quantum numbers concerned (in which case the quotients for a given term should be equal, by Landé's interval rule), the results are

a^3G, 21.7, 20.3; b^3F', 20.8, 23.5; c^3D, 24.1, 27.7; b^3P', 29.6, 31.2

These values run very smoothly and confirm the identification of c^3D as belonging to the pentad, rather than b^3D, for which the quotients are 43.1 and 31.2. The curious alternating arrangement of the energy levels of these terms, the F′ and P′ terms being nearly 4,000 units higher than the S, D, and G, which are close together, finds a parallel in pentads of similar origin in other spectra. The terms of the pentad belonging to the singlet system show a similar alternation in level, but in the opposite sense, the singlet P′ and F′ terms being at nearly the same level as the triplet S, D, and G, and vice versa (compare fig. 1). This remarkable relation may be commended to the attention of theoretical investigators of atomic structure.

VI. THE IONIZATION POTENTIAL FOR Sc II

The terms b^3D and c^1D are in series with the low terms a^3D and a^1D, being formed from them by the shift of an electron from a $4s$ to a $5s$ orbit. Applying a Rydberg formula to the various components of these terms, we find the term values given below. These represent the interval between the term component in question and the limits of the series to which each belong. In order to find the position of the series limit, relative to the adopted base level (the lowest energy state of Sc II) the observed term values, relative to this state, must be added.

From Hund's theory it follows that $^3D_3$ and $^1D_2$ go to the limit $^2D_3$ in Sc III, and $^3D_2$ and $^3D_1$ to $^2D_2$. If we wish to find the difference between the lowest energy levels of the singly and doubly ionized atom, we must therefore subtract the difference $^2D_3$–$^2D_2$, or 198, from the sum found in the first two cases.

The results are as follows:

Levels in Sc II	a^3D_3 178	a^3D_2 68	a^3D_1 0	a^1D_2 2,541
	b^3D_3 57,743	b^3D_2 57,614	b^3D_1 57,552	c^1D_2 58,252
Difference	57,565	57,546	57,552	55,711
Series terms	104,868	104,844	104,848	102,204
	47,304	47,296	47,300	46,492
Limit (above lowest level $^3D_1$)	105,046	104,911	104,848	104,745
Level in Sc III	198	0	0	198
$a^3D_1-3^2D_2$	104,848	104,911	104,848	104,547

The mean of the four determinations is 104,789, corresponding to an ionization potential of 12.94 volts. The greatest individual difference from the mean corresponds to only 0.03 volt. The term c^1D depends on but a single observed line, but the excellent agreement of the limits of the singlet and triplet series suffices to assure the correctness of both. The computed ionization potential is, however, probably a little too high, for in almost all cases when series involving changes in an *s* electron have been observed for several terms and Ritz formulas computed, it is found that a Rydberg formula applied to the first two terms gives somewhat too high a result, and 12.8 volts is probably nearer the truth. Menzel, from the conditions of appearance of the lines of Sc II in the stars, derived 12.5 volts.[23]

Taking the round number 104,000 (12.84 volts), we find the absolute values of the terms, for those cases in which an electron is added to various stages of Sc III, to be as follows:

TABLE 9.—*Energy for removal of electron Sc II*

Term Sc II	Limit Sc III	Added electron	Energy difference		n^*	Term Sc II	Limit Sc III	Added electron	Energy difference		n^*
			Wave numbers	Volts					Wave numbers	Volts	
$a\ ^3D_3$	$^2D_3$	4*s*	104,020	12.84	2.054	$b\ ^1G_4$	$^2D_3$	4*d*	38,962	4.81	3.355
$a\ ^1D_1$	$^2D_2$	4*s*	101,657	12.55	2.077	$a\ ^1F'_3$	$^2D_3$	4*d*	44,670	5.51	3.133
$b\ ^3D_3$	$^2D_3$	5*s*	46,457	5.74	3.073	$d\ ^1D_2$	$^2D_3$	4*d*	39,832	4.91	3.318
$c\ ^1D_3$	$^2D_3$	5*s*	45,946	5.68	3.090	$a\ ^1P_1$	$^2D_3$	4*d*	43,798	5.40	3.165
$a\ ^3F'_4$	$^2D_3$	3*d*	99,211	12.27	2.103	$b\ ^1S_0$	$^2D_3$	4*d*	39,256	4.85	3.343
$a\ ^3P'_4$	$^2D_3$	3*d*	92,044	11.36	2.183	$a\ ^3F_4$	$^2D_3$	4*p*	76,357	9.43	2.397
$a\ ^1G_4$	$^2D_3$	3*d*	89,937	11.10	2.208	$a\ ^3D'_3$	$^2D_3$	4*p*	76,037	9.39	2.402
$b\ ^1D_2$	$^2D_3$	3*d*	93,299	11.52	2.168	$a\ ^3P_2$	$^2D_3$	4*p*	74,374	9.18	2.429
$a\ ^1S_0$	$^2D_3$	3*d*	92,462	11.42	2.178	$a\ ^1F_3$	$^2D_3$	4*p*	71,848	8.87	2.471
$a\ ^3G_5$	$^2D_3$	4*d*	43,742	5.40	3.163						
						$a\ ^1D'_2$	$^2D_3$	4*p*	78,117	9.65	2.370
$b\ ^3F'_4$	$^2D_3$	4*d*	40,670	5.02	3.284	$a\ ^1P_1$	$^2D_3$	4*p*	73,382	9.06	2.445
$c\ ^3D_3$	$^2D_3$	4*d*	44,197	5.46	3.150	$b\ ^3P_2$	$^2S_1$	4*p*	90,176	11.14	2.206
$b\ ^3P'_2$	$^2D_3$	4*d*	39,493	4.88	3.333	$c\ ^3P'_2$	$^2P_2$	4*p*	89,982	11.11	2.208
$a\ ^3S_1$	$^2D_3$	4*d*	43,127	5.32	3.189						

[23] Harvard Observatory Circular 258; 1924.

The average values of the energy required to remove an electron from orbits of the various types, leaving the Sc III ion in its lowest energy state, with the corresponding effective quantum numbers n^* [24] and quantum defects, are as follows:

Electron	4*s*	5*s*	4*p*	3*d*	4*d*
Energy (volts)	12.71	5.71	9.26	11.57	5.16
n*	2.06	3.08	2.42	2.16	3.24
Quantum defect	1.94	1.92	1.58	.84	.76
Quantum defects for Sc III	1.61	1.61	1.30	.77	

The quantum defects are, as usual, greatest for the *s* electrons and least for the *d*. They are nearly the same for 4*s* and 5*s*, the individual differences being −0.019 for the ^{3}D terms and −0.013 for the ^{1}D. For 3*d* and 4*d* electrons, the difference is considerable, the ^{3}F′ terms giving −0.181; ^{3}P′, −0.150; ^{1}S, −0.165; ^{1}D, −0.150; and ^{1}G, −0.147. The close agreement of the last values with the others supports the identification of the upper ^{1}S and ^{1}G terms.

The corresponding quantum defects for Sc III, according to Gibbs and White, are given at the bottom. The greater values for Sc II indicate that the presence of the additional valency electron is not completely effective in neutralizing its share of the charge on the nucleus. The difference of the quantum defects is greatest for the *s* electron, indicating that the imperfection of the screening by the added electron is greatest when the electron which it is supposed to screen is in a deeply penetrating orbit. The energy of removal of a 4*p* electron, when the other valency electron is in a 4*s* or 4*p* orbit, is found above to be greater by almost two volts than when it is in a 3*d* orbit—that is, the screening effect of an electron in the more loosely bound orbits appears to be less.

It is now possible to estimate the probable values of the terms arising from other configurations. The configuration $(4s)^2$ should give an isolated ^{1}S term, which has not been observed. This is not surprising, for it should give strong combinations only with the ^{1}P term arising from the configuration 4*s*.4*p*, and this term has not been identified. For those coming from 3*d*.5*d* the Rydberg denominator should be from 4.2 to 4.4 and the term value (referred to ^{2}D of Sc III) between 22,000 and 25,000. The combinations of these terms with a^3F, etc., should be at or beyond λ2,000, and require a vacuum spectrograph for observation. They should be faint in any case. The multiplets arising from 3*d*.6*s* should be still farther in the ultraviolet and fainter. The configuration 3*d*.5*p* should give term values of the order of 35,000 to 40,000, and their combinations with the low terms, a^3D, etc., should also give lines in the Schumann region.

[24] These are the "Rydberg denominators" and for our purpose may be defined by the equation $n^*=3.68\ Z/\sqrt{I}$, when I is the ionization energy in volts, $Z=1$ for the neutral and 2 for the singly ionized atom, and 3.68 is the square root of the Rydberg constant, expressed in volts.

Finally, the configuration $3d.4f$ should give numerous terms, with denominators of the order of 3.9 (judging by other spectra) and term values about 30,000. Their combinations with the low terms should lie somewhere near λ1,500, and may give strong lines in this region. It appears, therefore, that all the lines of Sc II which might be anticipated in the observable region have been found.

VII. COMPARISON OF Sc II WITH Ca II

It is of interest to compare Ca II and Sc II, and notice how greatly the complexity of the spectrum is increased by the presence of two valency electrons instead of one. The principal terms in the former spectrum are the low even terms 4 ^{2}S and 3 ^{2}D, the odd term 4 ^{2}P, and the high even terms 5 ^{2}S and 4 ^{2}D. Transitions between these give lines as follows:

4S–4P λλ3,933, 3,968.
3D–4P 8,498, 8,542, 8,662.
4P–5S 3,737, 3,706.
4P–5D 3,159, 3,179, 3,181.

These 10 lines comprise practically the whole spectrum of Ca II outside the extreme ultra-violet (the combinations 5P–mD, etc., giving only very faint lines). The only other strong group is 3D–4F at λλ1,838, 1,840.

The corresponding electronic transitions in Sc II give rise to combinations between the following groups of terms.

Transition	Terms	Number of lines							
		Triplets		Singlets		Intercombinations		Total	
		c.	o.	c.	o.	c.	o.	c.	o.
$3d.4s$–$3d.4p$	$^3D, ^1D$ to $^3P, ^3D', ^3F, ^1P, ^1D', ^1F$	19	19	3	3	14	10	36	32
$(3d)^2$–$3p.4p$	$^3P', ^3F', ^1S, ^1D, ^1G$ to $^3P, ^3D', ^3F, ^1P, ^1D', ^1F$	25	25	5	5	20	5	50	35
$3d.4p$–$3d.5s$	$^3P, ^3D, ^3F, ^1P, ^1D, ^1F$ to $^3D, ^1D$	19	11	3	1	14	1	36	13
$3d.4p$–$3d.4d$	$^3P, ^3D', ^3F, ^1P, ^1D', ^1F$ to $^3S, ^3P', ^3D, ^3F', ^3G, ^1S, ^1P', ^1D, ^1F', ^1G$	53	42	9	9	40	1	102	52
$3d.4s$–$4s.4p$	$^3D, ^1D$ to $^3P, ^1P$	6	6	1	0	4	0	11	6
$4s.4p$–$(4p)^2$	$^1P, ^1P$ to $^3P', ^1S, ^1D$	6	5	2	0	6	0	14	5

The number of lines which should theoretically be produced by these transitions (excluding all cases in which the effective azimuthal quantum number changes by more than a unit) is given at the right, along with the number of lines in these groups so far observed. In the first two groups all the lines theoretically predicted have been observed except the fainter intercombinations; in the next two, which give weaker multiplets, the fainter lines in these, and almost all the intercombinations, have not been recorded.

All told, the presence of an additional $3d$ electron in the atom increases the theoretical number of lines corresponding to these four principal electron transitions from 10 to 224, 132 of which have actually been observed. The last two transitions, which have no direct correlatives in Ca II, should produce 27 lines, of which 11 have been observed.

VIII. INTERPRETATION OF THE TERMS OF Sc I

In the neutral atom there are three electrons, and the number of possible terms is greatly increased. Those which are to be anticipated are tabulated as before along with the observed terms which have been identified with them. The only difference is that the limiting term in Sc II, which corresponds to the removal of that electron which may be taken as the last to be bound, is also given. For the configuration $(3d)^3$, where Pauli's exclusion principle applies, no such limits for specific terms are given. The extreme separations of the terms are also tabulated.

Table 10.—Predicted and observed terms Sc I

Configuration	Added electron	Limit Sc II	Separation	Predicted terms	Observed terms and separations
$3d.\ (4s)^2$	$4s$	a^3D	178	^2D	$a\ ^2D(168)$
		a^1D			
$(3d)^2.4s$	$4s$	a^3F'	185	$^4F', ^2F'$	$a^4F'(158), c^2F'(116)$
		a^3P'	91	$^4P', ^2P'$	$a^4P'(81), a^2P'(80)$
		a^1G		^2G	$a^2G(-3)$
		b^1D		^2D	$b^2D(-12)$
		a^1S		^2S	
$(3d)^3$				$^4F', ^2H'$	$b^4F'(143)$
				$^4P', ^2G$	$b^4P'(80)$
				$^2F'$	
				^2D	
				$^2P'$	
				^2D	
$3d.4s.4p$	$4p$	a^3D	178	$^4P, ^4D', ^4F$	$a^4P(67), a^4D'(201), a^4F(354)$
				$^2P, ^2D', ^2F$	$a^2P(145), a^2D'(-74), a^2F(53)$
		a^1D		$^2P, ^2D', ^2F$	$b^2P(0), b^2D'(148), b^2F(140)$
$(3d)^2.4p$	$4p$	a^3F'	185	$^4D', ^4F, ^4G'$	$b^4D'(104), b^4F(176), a^4G'(281)$
				$^2D', ^2F, ^2G'$	$c^2D'(92), c^2F(125), a^2G'(95)$
		a^3P'	91	$^4S', ^4P, ^4D'$	$a^4S', c^4P(87)$
				$^2S', ^2P, ^2D'$	$a^2S'?$ ——, $x^2D'(54)?$
$(3d)^2.4p$	$4p$	a^1G		$^2F, ^2G', ^2H$	$d^2F(8), b^2G'(31), a^2H(96)$
		b^1D		$^2P, ^2D', ^2F$	$d^2P(-39), d^2D(105)$
		a^1S		^2P	$c^2P(133)$
$3d.4s.5s$	$5s$	a^3D	178	$^4D, ^2D$	$a^4D(177), c^2D(75)$
		a^1D		D	
$(3d)^2.5s$	$5s$	a^3F'	185	$^4F', ^2F'$	$d^4F'(163)$
		a^3P'	21	$^4P', ^2P'$	
		a^1G		^2G	
		b^1D		^2D	
		a^1S		^2S	
$3d.4s.4d$	$4d$	a^3D	178	$^4S, P', ^4D, ^4F', ^4G$	--, --, $b^4D(99), c^4F'(150), a^4G(167)$
				$^2S, ^2P', ^2D, ^2F', ^2G$	--, $b^2P(63), e^2D(75), b^2F'(88), b^2G$ (86)
		a^1D		$^2S, ^2P', ^2D, ^2F', ^2G$	
$(4p)^2.3d$	$3d$	c^3P'	346	$^4P', ^4D, ^4F'$	--, --, $e^4F'(303)$
				$^2P', ^2D, ^2F'$	
		^1S		^2D	
		^1D		$^2S, ^2P', ^2D, ^2F', ^2G$	

The identification of the lowest term, a^2D, as due to the configuration $3d.(4s)^2$ was made by Hund, who also attributed a^4F tentatively to $(3d)^2.4s$. The assignment of a^2F', a^2G, and a^2D to the same configuration is clearly justified, and there can be no doubt about a^4P', though this term has not been connected with the rest of the quartets. The separations of those arc terms which are derived from triplet spark terms are comparable in magnitude to those of the latter. For the doublet arc terms derived from singlet spark terms, the separations are small and negative.

The separation of the doubtful term a^2P' is of the right order, and supports its reality.

Passing next to the odd terms, the triad a^4P, a^4D', a^4F, evidently arises from $3d.4s.4p$, and b^4D', b^4F, a^4G' from $(3d)^2.4p$. Both should give strong combinations with a^4F', and the latter does, while the former should give lines far in the infra-red, beyond 2μ. Of the third triad of quartet terms, combining strongly with a^4P', two have been observed.

The odd doublet terms show several conspicuous triads. The group c^2D', c^2F, a^2G', for example, are all at nearly the same level and all combine much more strongly with a^2F' than with any other term, so that their place in the scheme is obvious. The triad d^2F, d^2G', a^2H has an exactly similar relation with a^2G. Of the triad which should combine most strongly with b^2D, two members are known, and the same appears to be true of the triad related to a^2P'.

There should be two triads combining strongly with a^2D—one having the limit a^3D and the other a^1D. These conditions are met by the groups a^2P, a^2D', a^2F, and b^2P, b^2D', b^2F, but it is difficult to be sure which of them is to be assigned to one limit and which to the other, and the two are bracketed in the table to indicate that the assignment is to this degree uncertain. The second triad gives much the strongest lines, including the *raies ultimes* of the arc spectrum.

Triads evidently analogous to these two are found in all the spectra from scandium to manganese, and probably as far as copper. It may be possible by a general study of their behavior to remove the uncertainty.

NOTE ADDED IN PROOF.—Such a study has shown that the lower triad has the limit a^1D and the upper triad a^3D.

There remains one isolated odd term c^2P, which presumably arises from a ^1S term in the spark and has been assigned to a^1S, though it lies rather low for this origin.

The high even terms are much less numerous than theory indicates, and it is evident that only the stronger combinations have been observed. Among the quartets d^4F', which combines with a^4G' and has very nearly the same separation as a^4F', is doubtless in series with

the latter, arising from $(3d)^2 .5s$. Its combinations with the rest of the triad lie in the infra-red. Similarly a^4D, which combines strongly with the triad a^4P, a^4D′, a^4F, must arise from $3d.4s.5s$. There are two other terms, b^4F′ and b^4P′, not far from the same level, which are just what might be anticipated from $(3d)^3$ and have been so assigned. They lie much higher than those of origin $(3d)^2.4s$ or $3d.\ (4s)^2$, but in Ca I the terms of origin $(3d)^2$ also lie much higher than those coming from $3d.4s$ or $(4s)^2$. These terms should combine strongly with the triad b^4D′, b^4F, a^4G′; but once more the anticipated lines lie far in the infra-red. The terms a^4G, c^4F′, b^4D combine with the triad a^4F, etc., and are clearly part of the pentad of origin $3d.4s.4d$. The ^{4}F term is higher than the other two, just as in the corresponding pentad in Sc II. This leaves only e^4F and f^4F. The very wide separation of the former suggests that its limit is the wide term c^3P′ of Sc II and that it comes from the configuration $(4p)^2.3d$; and this is fully confirmed by the fact that it, alone of all the high even terms, combines with terms belonging to both the $3d.4s.4p$ and $(3d)^2.4p$ triads, both transitions in this case involving the change of but one electron orbit. The term f^4F has not been definitely assigned. It involves only faint lines, and some of the intervals are so irregular as to suggest that parts of two different terms are concerned.

Among the high doublet terms, there are four ($b\ ^2$P′, $e\ ^2$D, $b\ ^2$F′, $b\ ^2$G) which lie near the same level and give strong combinations with the triad $b\ ^2$P, $b\ ^2$D′, $b\ ^2$F. These evidently belong to the pentad of origin $3d.\ 4s.\ 4d$. The term $c\ ^2$D, which gives a very strong combination with $a\ ^2$F of the lowest triad, has been assigned to $3d.\ 4s.\ 5s$.—a conclusion supported by series relations (see below). The term $d\ ^2$D, which lies a little higher, may belong either to this configuration, with limit $a\ ^1$D, or more probably to $(3d)^3$, while $f\ ^2$D can not be definitely assigned.

IX. THE IONIZATION POTENTIAL FOR Sc I

On the assumptions just made, two series are available for determination of the ionization potential, one comprising the terms $a\ ^2$D and $c\ ^2$D, and going to $a\ ^3$D of Sc II as limit, the other of $a\ ^4$F′ and $d\ ^4$F, with $a\ ^3$F as limit.

Treating these terms just as was done in the case of Sc II, six independent values may be found for the difference between the base levels of Sc I and Sc II, as follows:

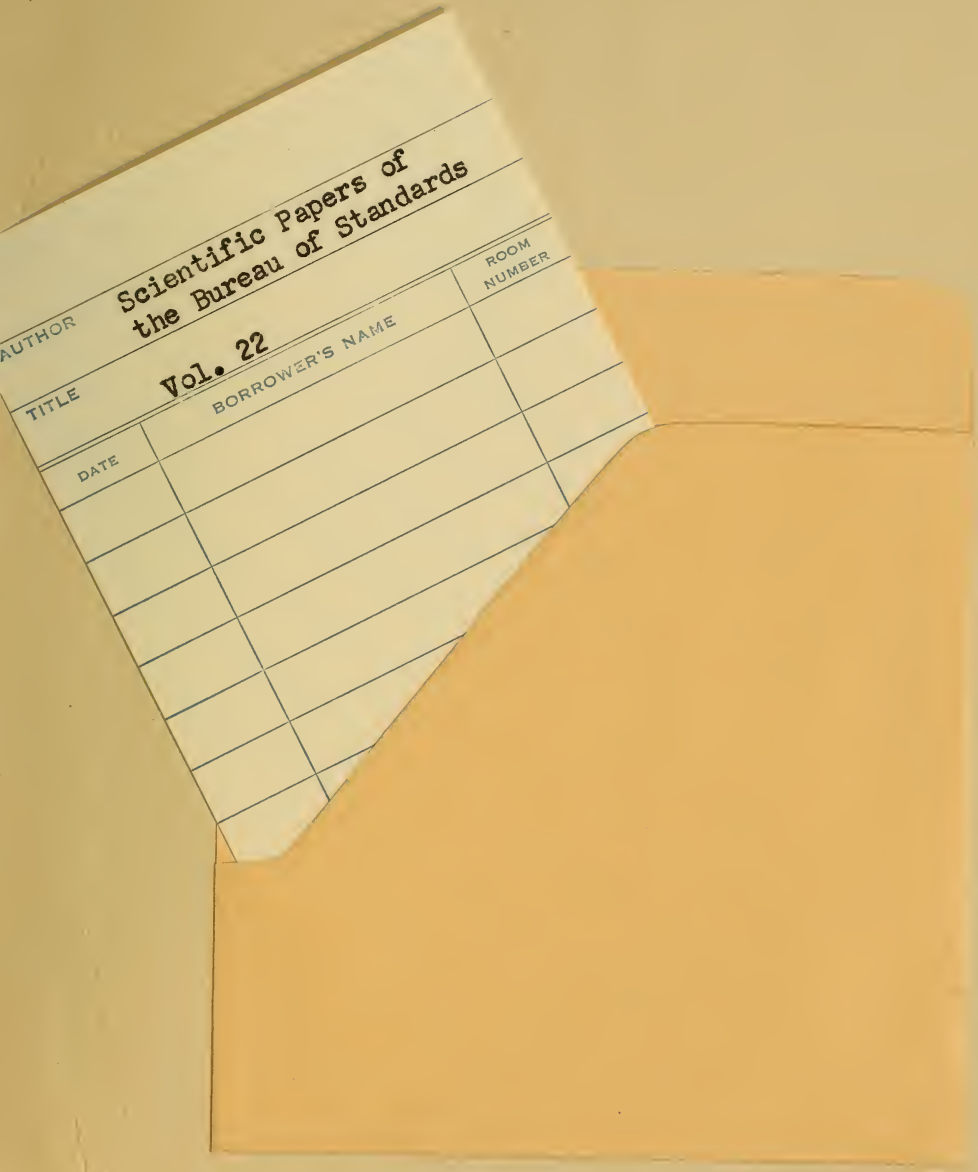
Observed levels	$^4F_5$	$^4F_4$	$^4F_3$	$^4F_2$	$^2D_3$	$^2D_2$	$^4D_4$?
Sc I	11,677 42,085	11,610 42,016	11,558 41,961	11,520 41,972	168 35,746	0 35,671	34,567 44,599
Series terms	47,737 17,329	47,733 17,328	47,730 17,327	47,729 17,327	54,285 18,706	54,401 18,730	19,976 9,944
Limit	59,414	59,343	59,288	59,249	54,453	54,401	54,343
Level in Sc II	4,988	4,883	4,803	4,803	178	68	178
$a^3D_1-a^2D_2$	54,426	54,460	54,485	54,446	54,276	54,333	54,165

The agreement of the results is again excellent, and fully confirms the reality of the series relations. The mean of the results, 54,406, corresponds to an ionization potential of 6.72 volts, which, as in other cases where a simple Rydberg formula must be used, is probably a little high. The true value is probably between 6.6 and 6.7 volts, intermediate between those for calcium (6.1) and titanium (6.8). This is in agreement with King's observation[25] that the enhanced lines of scandium are harder to produce in the furnace than those of the former, and easier than those of the latter.

Of the other series which might be anticipated, that beginning with $a\ ^2F'$ would give lines in the infra-red. It is possible that the term in sequence with $a\ ^4D$ might give observable lines, and there is a faint line at λ 3,498.91 ($n=28{,}572.18$), which is just in the right place to be the strongest member of the multiplet $a\ ^4F_5-c\ ^4D_4$, where $c\ ^4D_4=44{,}598.80$, and this has been entered tentatively in the table above. The resulting limit is very close to the others; but the reality of this term is uncertain, since no combination with $a\ ^4D'$ has been found.

Adopting the value 54,000 (6.67 volts) for $a\ ^2D_2-a\ ^3D_1$, we find the following values for the energy required to remove an electron from a neutral atom of scandium in its various energy states.

[25] Ap. J., 54, p. 40; 1921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